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⑤発明の名称　光走査装置

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明　細　書

1. 発明の名称　光走査装置

2. 特許請求の範囲

(1) 細い光束を出射する光源と、該光束を所定の方向に偏向走査する偏向器と、該偏向器で偏向された光束を被走査平面上に結像させる走査用レンズとを備え、前記走査用レンズは、前記偏向器の固有の回動特性で偏向された光束が被走査平面上では等速で移動する歪み特性を有し、かつ被走査平面上の任意の位置における光束の像面湾曲収差が零またはほとんど零となる如く両面が非球面で構成された単玉レンズであることを特徴とする光走査装置。

(2) 前記光源から出射された細い光束は前記走査用レンズに入射する直前は平行光束であることを特徴とする特許請求の範囲第1項記載の光走査装置。

3. 発明の詳細な説明

〔産業上の利用分野〕

本発明はレーザービームプリンタ等に用いられる光走査装置に関する。さらに詳しくは走査レンズ系に関する。

〔発明の技術的背景〕

レーザービーム等を高速に偏向走査して画像情報を記録するレーザービームプリンタは、高速、高解像度、低騒音という優れた特徴を有し、小型化低価格化が進むにつれ急速に[illegible]してきている。そこで、その[illegible]に対して[illegible]る光書き込みヘッドとして[illegible]走査装置は[illegible]レンズ系とからも小型化低価格化の[illegible]化は小型化低[illegible]大きくわけて光源[illegible]成るが、中で[illegible]回動特性にあわせて走[illegible]価格化に多面鏡であつて光ビームが等速で移動するような歪み、[illegible]走[illegible]いる時は偏向角θと像高Yが比

例するような歪みを有し、かつ走査平面上のいたる所で光スポットを所望の径に均一に結像する機能を有さなければならない。さらに回転多面鏡偏向器の場合には多面鏡の各面の傾きのばらつき（面倒れ誤差）を補償するための面倒れ補正機能も必要となる。これらの機能を兼ね備えた解像力の高い高性能な走査用レンズは従来必然的に大型・複雑で高価なものにならざるを得なかつた。

〔従来の技術〕

そこで特開昭54－98627、特開昭55－7727、特開昭58－5706等に開示されているように走査用レンズの単玉化が試みられている。ところが、特開昭54－98627では正弦振動特性を有する偏向器に対してはその回動特性を利用して形状等のパラメータの種々の値について幅広く良好に収差補正が可能であるが、高速性等の点から現在最も広く使用されている回転多面鏡偏向器の等角速度回動特性に対してはそれに対応するために非球面化しているものの特殊な場合としてきわめて限られた条件でしか使用できず、光学系の寸法、光源、必要とするドット径等の種々の要求に柔軟に対応することができない。

また、特開昭55－7727では平凸レンズでfθレンズを構成しているが、像面湾曲等の点で良好な結像性能を有しているとはいい難い。

また、特開昭58－5706では正のパワーを有するメニスカスレンズでfθレンズを構成しているが、球欠像面湾曲の点で問題があり、これを解消するために面倒れ補正光学系を兼ねる円筒レンズを付加しなくてはならない。さらに、上記3例はすべて面倒れ補正機能を付与するためには新たにレンズを付加しなければならず、結局単玉レンズでなくなつてしまう。また光軸長を長くとつて偏向角を狭めることによつて収差を許容範囲内に収めることは可能であるが、光学系全体が大型化するため好ましくない。

ところで、小型化低価格化を考えるうえでレンズの材質も重要な問題である。従来走査用レンズの材質にはガラスが用いられているが回折限界の性能を要求される光学系であつて要求精度が高いため、研摩等の製造コストが高くつく。そこでポリメチルメタクリレート（ＰＭＭＡ）ポリカーボネートポリスチレン等のプラスチックをレンズ材質に用いれば、射出成形による大量生産が可能となるため極めて安価に製造できる。ところが光学プラスチック材料は種類が少なくしかもガラスに比べ高屈折率のものがない。従つてレンズ枚数の削減や光学系の小型化がガラスに比べより困難である。

これらの点を総合して、材質の屈折率によらず単玉でしかも光軸長が短くても収差を良好に補正できるような、自由度の大きなレンズ形状が望まれることがわかる。

〔発明の解決しようとする問題点〕

本発明は上述のような問題点に鑑みてなされたもので、その目的は、小型で低価格、しかも高性能な光走査装置とくに走査用レンズを提供することである。

上記の目的のため、本発明の光走査装置は、細い光束を出射する光源と、該光束を所定の方向に偏向走査する偏向器と、該偏向器で偏向された光束を被走査平面上に結像させる走査用レンズとを備え、前記走査用レンズは、前記偏向器の固有の回動特性で偏向された光束が被走査平面上では等速で移動する歪み特性を有し、かつ被走査平面上の任意の位置における光束の像面湾曲収差が零またはほとんど零となる如く両面が非球面で構成された単玉レンズであることを特徴とする。また望ましくは前記光源から出射された細い光束は平行光束であることを特徴とする。

〔問題点を解決するための手段〕

本発明の光走査装置は、細い光束を出射する光源と、該光束を所定の方向に偏向走査する偏向器と、該偏向器で偏向された光束を被走査平面上に結像させる走査用レンズとを備え、前記走査用レンズは、前記偏向器の固有の回動特性で偏向された光束が被走査平面上では等速で移動する歪み特性を有し、かつ被走査平面上の任意の位置における光束の像面湾曲収差が零またはほとんど零となる如く両面が非球面で構成された単玉レンズであ

ることを特徴とする。

〔実施例〕

本発明の原理を第1図、第2図、第3図、第4図を用いて以下に説明する。

走査用レンズは、前述したように偏向器によつて等角速度あるいは正弦振動等の回動特性で偏向されている光束を被走査平面上に像面湾曲なく結像しまた被走査平面上で像点が等速で走査されるような歪みを与える機能を有する。例えば偏向器が回転多面鏡であれば、第1図に示されるように光源から出射した光束は鏡面 s_0 によつて多面鏡5の回転に応じた偏向角 θ で反射されている。走査用レンズ1はこの光束を被走査平面上で座標値Yが偏向角 θ と比例した点 T_1 に結像するよう設定される。本発明の走査用レンズは以下に述べる原理に基づいて第1図に示す s_1、s_2 の両面において非球面の特長が高度に利用された、収差が少なくしかも広角偏向が可能な単玉レンズである。

本発明に係るレンズ面形状の第1の構成原理は、走査される光束が非常に細いと仮定して、光束を主光線の位置と方向と結像距離のパラメータのみで表し、レンズ面上のある一点はそこを通る主光線のみについて方向あるいは結像距離を変化させるべく傾きと曲率が定められている、ということである。これを収差補正の考え方でいえば、球面収差とコマ収差を無視して像面湾曲収差と歪曲収差を高次の項まで含めて完全に補正するということを意味する。上述の仮定はレーザービームプリンタ等の走査光学系では一般に十分成立する。

さらに走査レンズ系は、任意の偏光角で偏向された光束の主光線は必ず同一平面上にある（これを子午面と呼ぶ）から、光束が非常に細いこととあわせて、面上で傾きと曲率が指定される点は、子午面とレンズ面が交わつた曲線上だけでよいことがわかる。従つて本発明の第2の構成原理は子午面上に曲線を創成して、その曲線上の任意の点において子午面内の傾きと曲率とが前述の走査用レンズの目的を達しており、さらに曲線上の任意の点において主光線を含み子午面に垂直な断面（球欠断面と呼ぶ）の曲率が与えられれば面が形成できたとすることである。

ただし、子午方向の傾きと曲率はそれを連続的に接続して子午面内のレンズ面位置を形成するためそれぞれ独立には定められないが、球欠断面曲率はそれらとは独立に扱える。従つて、子午面内のレンズ面形状のみについて上記第1第2の構成原理を適用した光学系も当然本発明の範囲に含まれることは明らかである。

以下、第2図の斜視図を用いて本発明に係るレンズの構成原理を具体的に説明する。

第1図において光束 $\{L_{i-1}\}'$ は面 S_i によつて光束 $\{L_i\}$ に変換される。光束 $\{L_i\}$ の T_i から測つた結像距離を子午光束で g_{mi}、球欠光束で g_{si} とする。一般に g_{mi} と g_{si} は等しくない。前述したように光束は非常に細いので光束 $\{L_i\}$ を扱うとき、主光線 L_{ci} と子午、球欠それぞれの結像距離 g_{mi}、g_{si} だけを考えればよい。さて、面 S_i を通過後の主光線 L_{xi} の方向は面 S_i の T_i における法線方向 ℓ_i で制御することができる。また面 s_i を通過後の結像距離 g_{ni}、g_{si} は面 s_i の T_i における子午断面曲率半径 R_{mi} と球欠断面曲率半径 R_{si} で制御することができる。従つてある角度で偏向された光束1本を走査平面上で等速走査が実現できる位置に結像させる機能をレンズ面上の1点の位置とその微分量（法線方向と曲率）で持たせることができたわけで、それを連続させて任意の角度で偏向された光束に対応したレンズ面上の各点に上記の機能を持たせれば目的とする走査用レンズ形状が定まるわけである。これが前述の第1の構成原 午面

さて、前述したように主光線 とℓi としてが
上を離れないため、面si 角αi の1
も子午面内にあり面の 断面曲率は面の
2図に示す光軸と 傾きαiは面siの
自由度でよい。 るから、結局子午面
傾きαi の 定することは微分方程
子午面 次元曲線を創成すること
ア がわかる。また、球欠断面

曲率は上記曲線に影響を与えず決定されるものであるから、曲線が創成された後その曲 上の各点についてそれぞれ決定される。これが第2の構成原理である。

以上述べた構成原理より走査用レンズが実現できるわけであるが、それが両非球面の単レンズで実現可能であることを第3図の原理図を用いて説明する。第3図において紙面は子午面を表している。

まず子午面内について考える。いま拘束したいのは主光線Lcと非走査平面s'の交点T'の座標値Y'とT'が結像点であることとの2自由度である。例えば任意の角度θで偏向されている光束の走査位置Y'を拘束するために面の傾きα_1を面上の全位置で指定し、それに従つて滑らかに面を接続した形状は境界条件（例えば光軸との交点P_1の座標値X_1とそこでの傾きが0であること）を指定すれば、S_1のように1通りに定まり、その面での曲率半径Rm_1を指定することはできず、光束は非走査平面上にない点T_1で結像してしまう。逆に、結像点を拘束するために面の曲率半径Rm_1を面上の全位置で指定すれば同様に面の傾きα_1を指定することはできない。このように光線の持つパラメータのうちある1つの自由度を偏向角θの任意の値で拘束するためには1つの面が必要であるから、今、上述の2自由度を拘束するために、最低2面のレンズ面が必要となる。

つぎに球欠光束について考えると、拘束したいのは球欠方向結像距離gs'の一自由度であつて、これは子午面内で拘束した状態すなわち曲線の形状を保存したまま、子午面上の曲線にそれと垂直な方向に曲率をつけることで制御できるため、前述の2面に新たに面を付け加える必要はない。

従つて必要なレンズ面は2面で、単玉レンズでよいことがわかる。また2面ともレンズ面の全位置で傾き、曲率が指定された面であるから単玉レンズは両非球面でなければならない。

さて、ここで上述の構成の単玉非球面レンズの面の対称性について考えてみる。子午面内に創成された2曲線を光軸等何らかの軸を中心にして回転させると球欠方向の曲率半径の自由度が失われてしまう。従つて回転対称性を持たせると球欠光束の結像を制御できず球欠像面湾曲収差が生じる。面対称性については、光束が常に子午面上にあるので明らかに子午面について対称であり、また光軸を通る光束を偏向角0として偏向角がθの光束と$-\theta$の光束とは同じ条件であるから光軸を含み子午面と垂直な平面についても対称である。このように本発明の走査用レンズは対称面が2面ある以外は対称性がないことによつて球欠像面湾曲収差、子午像面湾曲収差、歪曲特性収差の完全な補正が可能となつている。

以下本発明の走査用単玉両非球面レンズの形状を実現する具体的方法を第4図の原理図を用いて説明する。まず、子午面上の2曲線の創成方法を説明する。第4図に示すようにレンズ面S_1、S_2はそれぞれ光軸との交点P_1、P_2から曲線に沿つた距離s_1、s_2とその点での光軸に垂直な方向からの傾き角α_1、α_2との関係で規定されている。これを直交座標で表現し直すと、面S_1、S_2について、それぞれP_1、P_2を原点として光軸をx軸、レンズの高さ方向をy軸とすると、点P_1、P_2の座標値(x_1, y_1)、(x_2, y_2)は

$$x_1 = \int_0^{s_1} \sin\alpha_1 \, ds_1$$

$$y_1 = \int_0^{s_1} \cos\alpha_1 \, ds_1$$

$$x_2 = \int_0^{s_2} \sin\alpha_2 \, ds_2 \qquad (1)$$

$$y_2 = \int_0^{s_2} \cos\alpha_2 \, ds_2$$

となる。

いま、第4図に示すように、光軸上の出射点F_0から偏向角θ、子午結像距離gm'で出射した光束L_i（i＝0，1，2）が面S_1、S_2とそれぞれT_1、T_2で、像面S'とT'で交わるとし、以下のように光束の出射位置、出射方向を表わす。すなわち

$$\vec{PT_1}=\ell_0\begin{pmatrix}\cos\theta\\ \sin\theta\end{pmatrix}$$

$$\vec{T_1T_2}=\ell_1\begin{pmatrix}\cos\theta_1\\ \sin\theta_1\end{pmatrix} \qquad (2)$$

$$\vec{T_2T_1}=\ell_2\begin{pmatrix}\cos\theta_2\\ \sin\theta_2\end{pmatrix}$$

とする。さらに面S_1, S_2のT_1, T_2での子午断面曲率半径をそれぞれR_{m1}, R_{m2}とし、また、光束L_1, L_2の子午結像距離をg_{m1}, g_{m2}とする。

以上の記述方法に従つて、前述したレンズ形状の構成原理を定式化することができる。定式化を以下に示す6項目に分けて説明する。

① 面S_1, S_2と光束の交点において面の傾きによつて光束の方向を制御する。

② 面S_1, S_2と光束の交点において面の曲率によつて光束の結像距離を制御する。

③ 面と光束の交点の座標が等しい。

④ 面上の各点は滑らかに連続している。

⑤ 光束は走査平面上に結像する。

⑥ 走査平面上で結像点は等速走査される。

①の屈折面の傾きと光束の方向の関係は、よく知られた屈折の法則をS_1, S_2面とL_1, L_2の交点について適用することによつて

$$\sin(\alpha_1-\theta)=n\sin(\alpha_1-\theta_1) \quad : S_1\text{面} \qquad (3)$$

$$n\sin(\alpha_2-\theta_1)=\sin(\alpha_2-\theta_2) \quad : S_2\text{面} \qquad (4)$$

と表わせる。ただしnはレンズ媒質の屈折率である。

②の面の曲率と光束の結像距離の関係は、細い光束がある曲率を持つた面に斜め入射した時の子午結像距離の関係式をS_1面, S_2面に適用して

$$\frac{n\cos^2(\alpha_1-\theta_1)}{g_{m1}}=\frac{\cos^2(\alpha_1-\theta)}{g_{m0}-\ell_0}+\frac{n\cos(\alpha_1-\theta_1)-\cos(\alpha_1-\theta)}{R_{m1}} \qquad (5)$$

S_1面

$$\frac{\cos^2(\alpha_2-\theta_2)}{g_{m2}}=\frac{n\cos^2(\alpha_2-\theta_1)}{g_{m1}-\ell_1}+\frac{\cos(\alpha_2-\theta_2)-n\cos(\alpha_2-\theta_1)}{R_{m2}} \qquad (6)$$

S_2面

が得られる。

③については、前出の(1)式で計算される面位置の直交座標値と前出の(2)式をもとに計算される光線の屈折点の直交座標値が等しいとおいて、

$$\ell_0\cos\theta=\int_0^{s_1}\sin\alpha_1 ds_1+X_1 \qquad (7)$$

$$\ell_0\sin\theta=\int_0^{s_1}\cos\alpha_1 ds_1 \qquad (8)$$

$$\ell_1\cos\theta_1+\ell_0\cos\theta=\int_0^{s_2}\sin\alpha_2 ds_2+X_2 \qquad (9)$$

$$\ell_1\sin\theta_1+\ell_0\sin\theta=\int_0^{s_2}\cos\alpha_2 ds_2 \qquad (10)$$

の関係がある。ただしX_1は面S_1と光軸の交点のx座標値、X_2は面S_2と光軸の交点のx座標値である。

④について、面が連続している条件は、(7)〜(10)式中の積分が可能であるということである。また面が滑らかである条件は、面の傾きα_1, α_2が微分可能であるということであつて

$$\frac{d\alpha_1}{ds_1}=\frac{1}{R_{m1}} \qquad (11)$$

$$\frac{d\alpha_2}{ds_2}=\frac{1}{R_{m2}} \qquad (12)$$

なる関係がある。

⑤の走査平面上で像点が等速走査される条件は像面と光束の交点(X_1, Y_1)が

$$X_1=\ell_2\cos\theta_2+\ell_1\cos\theta_1+\ell_0\cos\theta \qquad (13)$$

$$Y_1=\ell_2\sin\theta_2+\ell_1\sin\theta_1+\ell_0\sin\theta \qquad (14)$$

の関係があつて、かつ走査点位置Y_1は、偏向器の回動特性

$$\theta=F(t) \qquad (15)$$

を用いて

$$Y_1=K\cdot F^{-1}(\theta) \qquad (16)$$

となる。ただしF^{-1}はFの逆関数、tは時間のパラメータ、Kは適当な比例定数である。例えば今、回動特性が等角速度偏向であつた場合、

$$F(t)=\omega t \qquad \omega:\text{角速度} \qquad (17)$$

であるから

$$Y_1=K\cdot\frac{\theta}{\omega}$$

$$=f\theta \qquad f=\frac{K}{\omega}:\text{定数} \qquad (18)$$

と書ける。また(13)式のX　は走査面のx座標で光軸長を表している。

⑥の走査平面上で結像する条件は、(6)式中の子午光束結像距離g_{m2}が(13)、(14)式で与われるℓ_2に等しければ満足される。即ち

$$g_{m2}-\ell_2 \qquad (16)$$

以上のようにして本発明に係るレンズ形状の構成原理が(3)(4)(5)(6)(7)(8)(9)(10)(11)(12)(13)(14)(15)(16)の14式で定式化されたわけだが、以下これらを計算することによつて実際にレンズ面形状が何らかの形で直接表現できることを述べる。式中に現れた変数のうち偏向角θ、初期子午結像距離g_{m0}は出射時に与えられており既知である。また光路長X_1，面S_1，S_2の光軸との交点位置X_1，X_2，等速走査の定数Kは偏向角θによらない定数値である。従つて未知数は残つたθ_1，θ_2，α_1，α_2，s_1，s_2，g_{m1}，g_{m2}，ℓ_0，ℓ_1，ℓ_2，R_{m1}，R_{m2}，Y_1の14個であつて、前出の14式はすべて独立であるから、連立方程式は解けて上記14変数は例えば偏向角θの関数として表現できる。従つて例えば面S_1を表現する時は傾きα_1と光軸から面に沿つた距離s_1の関係を偏向角θをパラメータとして対応させればよい。

ところで、上述の14元連立方程式は非線形でかつ微分項と積分項を含んでいるため、直接解くことはできず数値解法を用いなければならない。数値解法としては種々考えられ本発明はそれを限定するものではないが、ここでは一実施例として、差分ベクトル法における数値積分の方法で実際にこの方程式が数値計算で解けレンズ形状が決定できることを示しておく。

差分ベクトル法で解くとは、方程式をすべて微分形式で表して現在の変数の値はすべて既知としてそれぞれの変数の微分(差分変数)を計算して次の変数の値を求めるというものである。前出14式を整理して微分形で表すと、(3)(4)式は

$$(d\alpha_1-d\theta)\cos(\alpha_1-\theta)=n(d\alpha_1-d\theta_1)\cos(\alpha_1-\theta_1) \qquad (21)$$

$$n(d\alpha_2-d\theta_1)\cos(\alpha_2-\theta_1)=(d\alpha_2-d\theta_2)\cos(\alpha_2-\theta_2) \qquad (22)$$

(5)(6)式と(21)(22)式をあわせて

$$\frac{n\cos^2(\alpha_1-\theta_1)}{g_{m1}}ds_1=\frac{\cos^2(\alpha_1-\theta)}{g_{m0}-\ell_0}ds_1+\{n\cos(\alpha_1-\theta_1)-\cos(\alpha_1-\theta)\}d\alpha_1 \qquad (23)$$

$$\frac{\cos^2(\alpha_2-\theta_2)}{g_{m2}}ds_2=\frac{\cos^2(\alpha_2-\theta_1)}{g_{m1}-\ell_1}ds_2+\{\cos(\alpha_2-\theta_2)-n\cos(\alpha_2-\theta_1)\}d\alpha_2 \qquad (24)$$

ただしg_{m1}は(23)(24)式を連立させて消去する。

また(7)～(10)式は

$$d\ell_0\cos\theta-\ell_0\sin\theta d\theta=\sin\alpha_1 ds_1 \qquad (25)$$

$$d\ell_0\sin\theta+\ell_0\cos\theta d\theta=\cos\alpha_1 ds_1 \qquad (26)$$

$$d\ell_1\cos\theta_1-\ell_1\sin\theta_1 d\theta_1+d\ell_0\cos\theta-\ell_0\sin\theta d\theta=\sin\alpha_2 ds_2 \qquad (27)$$

$$d\ell_1\sin\theta_1+\ell_1\cos\theta_1 d\theta_1+d\ell_0\sin\theta+\ell_0\cos\theta d\theta=\cos\alpha_2 ds_2 \qquad (28)$$

(13)(14)式は

$$0=d\ell_2\cos\theta_2-\ell_2\sin\theta_2 d\theta_2+d\ell_1\cos\theta_1-\ell_1\sin\theta_1 d\theta_1+d\ell_0\cos\theta-\ell_0\sin\theta d\theta \qquad (29)$$

$$dY_1=d\ell_2\sin\theta_2+\ell_2\cos\theta_2 d\theta_2+d\ell_1\sin\theta_1+\ell_1\cos\theta_1 d\theta_1+d\ell_0\sin\theta+\ell_0\cos\theta d\theta \qquad (30)$$

(15)式は

$$dY_1=K\{F^{-1}(\theta)\}\cdot d\theta$$

となる。(15)式は単に代入すれば良い。(21)～(30)式のうち未知である差分変数は$d\theta_1$，$d\theta_2$，$d\alpha_1$，$d\alpha_2$，ds_1，ds_2，$d\ell_0$，$d\ell_1$，$d\ell_2$，dY_1であつて、上(21)～(30)式は(23)(24)式を連立させて1個の式にしたものが2次の方程式である以外はすべて1次であるから容易に解けて、既知の差分変数$d\theta$によつて例えば

$$d\theta_1=F_{\theta_1}(\theta_1,\theta_2,\alpha_1,\alpha_2,s_1,s_2,\ell_0,\ell_1,\ell_2)\cdot d\theta \qquad (31)$$

のように表現できる。これより例えばθ_1は、

$$\theta_1=\int_0^{\theta}F_{\theta_1}d\theta+\theta_1^{0} \qquad (32)$$

と積分すれば偏向角θをパラメータとして表現できる。ただしθ_1^{0}は初期値である。実際の計算は初期値をθ_1，θ_2，α_1，α_2，s_1，s_2については0，ℓ_0，ℓ_1，ℓ_2については前出のX_1，X_2，X_3の値を用いて

$$\ell_0^{0}=X$$
$$\ell_1^{0}=X_2-X_1 \qquad (33)$$
$$\ell_2^{0}=X_1-X_2$$

として、数値積分によつて計算できる。

さて、以上のようにして本発明のレンズ形状の子午面上母線が具体化されるわけだが、具体化する過程で現れた定数n X_1，X_2，X_1，g_{m0}，Kはそのまま本発明のレンズ形状のとりうる自由度となる。すなわち、ある適当な定数の組$\{X_1^{*}, X_2^{*}, X_1^{*}, g_{m0}^{*}, K^{*}\}$の1つについて1つのレンズ形状

が存在するわけであり、当然本発明はこれらすべてのものを含んでいる。

なお、子午初期結像距離 g_{m0}^{*} を無限大に設定する。すなわち走査用レンズに入射する前の子午光束を平行光束としておけば、ビーム径等が制御し易く取扱い易い光学系となる。本発明の走査用レンズは上述のように平行光束に対しても当然適用可能である。

さて次に、球欠結像距離を制御する球欠断面曲率半径 R_{s1}, R_{s2} の決定方法を説明する。

(5)(6)式に細い光束が斜め入射した時の子午結像距離の関係式を示したが、球欠結像距離については、

$$\frac{n}{g_{s1}}=\frac{1}{g_{s0}-l_0}+\frac{n\cos(\alpha_1-\theta_1)-\cos(\alpha_1-\theta)}{R_{s1}}\quad S_1\text{面} \tag{34}$$

$$\frac{1}{g_{s2}}=\frac{n}{g_{s1}-l_1}+\frac{\cos(\alpha_2-\theta_2)-n\cos(\alpha_2-\theta_1)}{R_{s2}}\quad S_2\text{面} \tag{35}$$

が成立つ、被走査平面上に球欠方向の結像点がある条件は

$$g_{s2}=l_2 \tag{36}$$

である。(34),(35),(36)式によつて球欠断面曲率半径 R_{s1}, R_{s2} が決定されるわけであるが、式中で $l_0, l_1, l_2, \alpha_1, \alpha_2, \theta, \theta_1, \theta_2$ は前述の方法によつて子午面曲線がすでに決定されているため既知であり、g_{s0} は与えられているため未知数は $g_{s1}, g_{s2}, R_{s1}, R_{s2}$, の4個である。従つて方程式3個に対し冗長自由度があることになり、未知数のうち1つは適当に定めてよいことがわかる。例えば面形状の簡単化のため、R_{s1} を常に無限大にして(34)式の右辺第2項を0にすれば第1面は球欠方向に曲率を持たない面になる。

なお初期球欠結像距離 g_{s0} は任意に与えてよいが偏向器が回転多面鏡の場合、

$$g_{s0}=0$$

ととれば鏡面の反射点と走査点とが共役像点となつて面倒れ補正機能を持たせることができる。

〔実施例〕

本発明に係るレンズ形状の構成原理に基づいてレンズ面形状を計算した実施例を第1表から第9表までと第5図から第12図までに示す。

前述したように本発明のレンズ形状は、レンズ媒質の屈折率n、初期結像距離 g_0、レンズの第1面、第2面が光軸と交わる位置 X_1, X_2、光路長 X_l、走査速度定数Kの6個のパラメータをそれぞれ独立に変化させることができ、1つのパラメータの値の組に対して1つのレンズ形状が存在する。従つて一見して全く異質の形状と思われるような実施例が極めて多数存在し、それらすべてを掲げることは不可能であるため、ここには代表的な実施例を示すにとどめる。

以下に示す実施例に共通する計算条件は、

- レンズ媒質の屈折率　$n=1.486$
- 偏向点から被走査平面までの光軸長

  $X_l = 200$ mm
- 偏向器は回転多面鏡偏向器で等角速度偏向
- 初期子午結像距離 g_{m0} は無限大。すなわち走査用レンズに入射する前の光束は平行光束である。
- 球欠断面曲率は第2面にのみ付与してある。
- 初期球欠結像距離 g_{s0} は0。従つて回転多面鏡の反射点と走査点は共役像点となり、面倒れ補正機能が付与されている。

である。

なお本発明によるレンズ形状は簡単な数値や数式では表現されず、例えば数値例として結果が求まる。そこで便宜上、子午面上の曲線形状については周知の非球面係数を用いた式

$$x=\frac{\frac{y}{R}}{1+\sqrt{1-\left(\frac{y}{R}\right)^2}}+By^4+Cy^6+Dy^8+Ey^{10}$$

：ただしxは光軸をx軸、面と光軸の交点を原点にとつたときのx座標値。

で表し、第2面の球欠断面曲率 R_{s2} については

$$R_{s2}=R_{s2}^{0}+Ay^2+By^4+Cy^6+Dy^8+Ey^{10}$$

で表す。このように近似した時の真の形状からの誤差は0.001％〜0.01％程度である。

第1表，第2表，第3表に第1面 S_1 の子午平面上の曲線形状を示す係数 $R_{m1}, B_1, C_1, D_1, E_1$ を、第4表，第5表，第6表に第2面 S_2 の子午平面上の曲線形状を示す係数 R_{m2}, B_2, C_2, D_2,

E_2 を、第7表，第8表，第9表に球欠断面方向の曲率半径変化を示す係数 $R_s^{\circ}, A_s, B_s, C_s, D_s, E_s$ を、パラメータ θ_e, X_1, X_2 を変化させて計算した値を掲げる。ただし有効偏向角 θ_e は、前出 (18) 式の走査速度係数Kのかわりに用いたパラメータで、有効走査幅を200㎜と定めると、

$$\theta_e = \frac{200}{K} \qquad (\mathrm{rad})$$

である。X_1, X_2 は前出のとおり、第1面 S_1 第2面 S_2 が光軸と交わる点の位置である。なお、前述の共通の計算条件のもとで、パラメータの組 θ_e, X_1, X_2 の値が同じものは同一のレンズとなる。

さらに、表に示した実施例中のいくつかのものについて、子午面上の曲線形状の概観を、光路図とともに第5図から第12図までに示した。ただし曲線は光軸について対称であるため、光軸の逆側は省略してある。

ここで掲載された実施例はすべて本発明の構成原理に従つて、球欠像面湾曲収差、子午像面湾曲収差は完全に除去されており、また歪み特性は走査点が等速移動するように完全に定められている。

ただし、完全というのは理想的な状態であつて実際のレンズ形状には形状を算出する時の数値計算誤差、あるいは製造誤差等のため像面湾曲収差、歪曲特性収差が多少は生じる。もちろんそれらの収差にはある程度の許容範囲があり、その範囲内であれば走査用レンズとして有効であるから、本発明はそれらを除外するものではない。

第 1 表

θ_e (deg)	X_1 (mm)	X_2 (mm)	R_{m1} (mm)	B_1 (mm^{-3})	C_1 (mm^{-5})	D_1 (mm^{-7})	E_1 (mm^{-9})
40.	5.	20.	-19.12	-.2563E-03	-.4657E-05	.2897E-06	-.9263E-08
40.	5.	30.	-43.76	-.1100E-03	.1092E-05	.3293E-07	-.1242E-08
40.	5.	40.	-97.82	-.7842E-04	.1955E-05	-.2714E-07	.7920E-10
40.	5.	50.	-311.80	-.6947E-04	.2212E-05	-.4994E-07	.5573E-09
40.	5.	60.	795.84	-.6696E-04	.2333E-05	-.6099E-07	.7848E-09
40.	5.	70.	230.01	-.6678E-04	.2385E-05	-.6727E-07	.9119E-09
40.	5.	80.	151.19	-.6745E-04	.2424E-05	-.7124E-07	.9512E-09
40.	5.	90.	119.80	-.6842E-04	.2453E-05	-.7397E-07	.1045E-08
40.	5.	100.	102.93	-.6948E-04	.2478E-05	-.7597E-07	.1083E-08
40.	10.	30.	-35.01	-.5433E-04	-.3028E-06	.3814E-08	-.4657E-10
40.	10.	40.	-83.85	-.2669E-04	.6022E-07	.2794E-10	-.2229E-11
40.	10.	50.	-277.15	-.1928E-04	.1249E-06	-.6407E-09	.1583E-11
40.	10.	60.	723.21	-.1712E-04	.1413E-06	-.8950E-09	.2003E-11
40.	10.	70.	212.32	-.1667E-04	.1479E-06	-.1011E-08	.3318E-11
40.	10.	80.	141.11	-.1684E-04	.1516E-06	-.1071E-08	.3562E-11
40.	10.	90.	112.75	-.1725E-04	.1541E-06	-.1106E-08	.3705E-11
40.	10.	100.	97.81	-.1774E-04	.1561E-06	-.1130E-08	.3785E-11
40.	15.	40.	-69.87	-.1771E-04	-.2170E-07	.1296E-09	-.8952E-12
40.	15.	50.	-242.51	-.1007E-04	.2127E-07	-.4962E-10	.4138E-13
40.	15.	60.	650.08	-.7949E-05	.2831E-07	-.8007E-10	.1114E-12
40.	15.	70.	194.62	-.7473E-05	.3033E-07	-.9129E-10	.1307E-12
40.	15.	80.	131.03	-.7559E-05	.3120E-07	-.9590E-10	.1370E-12
40.	15.	90.	105.71	-.7846E-05	.3176E-07	-.9804E-10	.1389E-12
40.	15.	100.	92.09	-.8200E-05	.3222E-07	-.9922E-10	.1392E-12
40.	20.	50.	-207.86	-.7019E-05	.3905E-08	-.6111E-11	-.9146E-14
40.	20.	60.	578.86	-.4716E-05	.9172E-08	-.1497E-10	.1177E-13
40.	20.	70.	176.93	-.4220E-05	.1010E-07	-.1695E-10	.1337E-13
40.	20.	80.	120.95	-.4283E-05	.1037E-07	-.1751E-10	.1340E-13
40.	20.	90.	98.66	-.4530E-05	.1052E-07	-.1763E-10	.1327E-13
40.	20.	100.	88.60	-.4033E-05	.1067E-07	-.1765E-10	.1303E-13
40.	25.	50.	-173.22	-.5500E-05	-.6739E-08	.2403E-10	-.4943E-13
40.	25.	60.	506.23	-.3204E-05	.3051E-08	-.4216E-11	.2096E-14
40.	25.	70.	159.24	-.2670E-05	.4305E-08	-.4619E-11	.2262E-14
40.	25.	80.	110.87	-.2735E-05	.4445E-08	-.4638E-11	.2161E-14
40.	25.	90.	91.61	-.2975E-05	.4471E-08	-.4576E-11	.2053E-14
40.	25.	100.	81.26	-.3259E-05	.4519E-08	-.4524E-11	.1960E-14
40.	30.	60.	433.90	-.2364E-05	.1000E-08	-.1523E-11	.4737E-15
40.	30.	70.	141.54	-.1775E-05	.2250E-08	-.1569E-11	.5075E-15
40.	30.	80.	100.79	-.1860E-05	.2210E-08	-.1507E-11	.4487E-15
40.	30.	90.	84.56	-.2111E-05	.2179E-08	-.1444E-11	.4065E-15
40.	30.	100.	75.84	-.2394E-05	.2188E-08	-.1407E-11	.3796E-15
40.	35.	60.	361.50	-.1010E-05	.9673E-09	-.5353E-12	.2987E-16
40.	35.	70.	123.85	-.1157E-05	.1206E-08	-.5833E-12	.1260E-15
40.	35.	80.	90.71	-.1202E-05	.1166E-08	-.5140E-12	.9730E-16
40.	35.	90.	77.52	-.1562E-05	.1102E-08	-.4685E-12	.8106E-16
40.	35.	100.	70.42	-.1857E-05	.1090E-08	-.4514E-12	.7200E-16
40.	40.	60.	209.26	-.1292E-05	.1012E-09	.4200E-12	-.3159E-15

第 2 表

θ_c (deg)	X_1 (mm)	X_2 (mm)	R_{m1} (mm)	B_1 (mm^{-4})	C_1 (mm^{-6})	D_1 (mm^{-8})	E_1 (mm^{-10})
45.	5.	20.	-11.86	-.3306E-03	-.3374E-04	.2173E-05	-.8502E-07
45.	5.	30.	-24.39	-.1113E-03	-.1286E-05	.6509E-07	-.1421E-08
45.	5.	40.	-44.60	-.5490E-04	.4773E-06	.7759E-08	-.2449E-09
45.	5.	50.	-82.64	-.4102E-04	.9341E-06	-.1142E-07	.4620E-10
45.	5.	60.	-180.67	-.3898E-04	.1130E-05	-.1993E-07	.1634E-09
45.	5.	70.	-1011.26	-.4075E-04	.1247E-05	-.2448E-07	.2214E-09
45.	5.	80.	426.46	-.4374E-04	.1331E-05	-.2726E-07	.2543E-09
45.	5.	90.	204.32	-.4701E-04	.1397E-05	-.2915E-07	.2750E-09
45.	5.	100.	144.78	-.5022E-04	.1453E-05	-.3054E-07	.2891E-09
45.	5.	110.	117.15	-.5324E-04	.1501E-05	-.3161E-07	.2993E-09
45.	10.	40.	-38.23	-.3369E-04	-.2086E-06	.2106E-08	-.1987E-10
45.	10.	50.	-73.45	-.1780E-04	.1637E-07	.5596E-10	-.9349E-12
45.	10.	60.	-164.25	-.1245E-04	.5749E-07	-.2182E-09	.3566E-12
45.	10.	70.	-933.47	-.1093E-04	.7195E-07	-.3333E-09	.7303E-12
45.	10.	80.	398.03	-.1090E-04	.7922E-07	-.3896E-09	.8826E-12
45.	10.	90.	192.30	-.1145E-04	.8406E-07	-.4209E-09	.9527E-12
45.	10.	100.	137.16	-.1224E-04	.8790E-07	-.4405E-09	.9878E-12
45.	10.	110.	111.57	-.1309E-04	.9121E-07	-.4543E-09	.1007E-11
45.	15.	50.	-64.27	-.1285E-04	-.4923E-07	.2994E-09	-.1241E-11
45.	15.	60.	-147.82	-.7466E-05	.6297E-08	-.1171E-10	-.1223E-13
45.	15.	70.	-855.67	-.5443E-05	.1335E-07	-.2777E-10	.2676E-13
45.	15.	80.	369.60	-.4919E-05	.1561E-07	-.3349E-10	.3354E-13
45.	15.	90.	180.28	-.5010E-05	.1670E-07	-.3628E-10	.3531E-13
45.	15.	100.	129.54	-.5356E-05	.1744E-07	-.3732E-10	.3552E-13
45.	15.	110.	105.79	-.5799E-05	.1808E-07	-.3822E-10	.3524E-13
45.	20.	70.	-777.88	-.3520E-05	.3731E-08	-.4868E-11	.2205E-14
45.	20.	80.	341.17	-.2814E-05	.4987E-08	-.6023E-11	.3349E-14
45.	20.	90.	168.27	-.2748E-05	.5357E-08	-.6363E-11	.3346E-14
45.	20.	100.	121.92	-.2946E-05	.5538E-08	-.6416E-11	.3206E-14
45.	20.	110.	100.41	-.3248E-05	.5688E-08	-.6388E-11	.3053E-14
45.	25.	70.	-700.08	-.2623E-05	.8373E-09	-.5031E-12	-.8496E-15
45.	25.	80.	312.73	-.1818E-05	.2073E-08	-.1595E-11	.5635E-15
45.	25.	90.	156.25	-.1678E-05	.2218E-08	-.1609E-11	.5113E-15
45.	25.	100.	114.30	-.1812E-05	.2231E-08	-.1548E-11	.4523E-15
45.	25.	110.	94.84	-.2053E-05	.2241E-08	-.1478E-11	.4027E-15
45.	30.	80.	284.30	-.1254E-05	.1021E-08	-.5364E-12	.1309E-15
45.	30.	90.	144.23	-.1066E-05	.1063E-08	-.4895E-12	.9811E-16
45.	30.	100.	106.68	-.1166E-05	.9976E-09	-.4236E-12	.7365E-16
45.	30.	110.	89.26	-.1371E-05	.9416E-09	-.3650E-12	.5602E-16
45.	35.	80.	255.87	-.8862E-06	.5693E-09	-.2077E-12	.3834E-16
45.	35.	90.	132.21	-.6331E-06	.5031E-09	-.1293E-12	.1505E-16
45.	40.	80.	227.44	-.6081E-06	.3567E-09	-.8526E-13	.1540E-16

第 3 表

θ_c (deg)	X_1 (mm)	X_2 (mm)	R_{m1} (mm)	B_1 (mm^{-4})	C_1 (mm^{-6})	D_1 (mm^{-8})	E_1 (mm^{-10})
50.	5.	40.	-28.89	-.7902E-04	-.2588E-06	.1257E-07	-.2687E-09
50.	5.	50.	-47.63	-.4704E-04	.5388E-06	-.3995E-08	-.666CE-11
50.	5.	60.	-81.12	-.3908E-04	.7970E-06	-.1032E-07	.5914E-10
50.	5.	70.	-158.09	-.3738E-04	.9276E-06	-.1342E-07	.8594E-10
50.	5.	80.	-519.65	-.3522E-04	.1019E-05	-.1525E-07	.9939E-10
50.	5.	90.	693.91	-.4363E-04	.1097E-05	-.1653E-07	.1075E-09
50.	5.	100.	244.02	-.4785E-04	.1169E-05	-.1757E-07	.1133E-09
50.	5.	110.	160.03	-.5220E-04	.1239E-05	-.1852E-07	.1183E-09
50.	5.	120.	124.60	-.5659E-04	.1312E-05	-.1947E-07	.1233E-09
50.	5.	130.	105.06	-.6104E-04	.1391E-05	-.2052E-07	.1289E-09
50.	10.	60.	-73.75	-.1788E-04	.1196E-07	-.2219E-10	-.5287E-12
50.	10.	70.	-145.93	-.1320E-04	.4743E-07	-.1714E-09	.2455E-12
50.	10.	80.	-485.00	-.1159E-04	.5967E-07	-.2182E-09	.3563E-12
50.	10.	90.	653.10	-.1141E-04	.6597E-07	-.2419E-09	.3887E-12
50.	10.	100.	231.17	-.1190E-04	.7040E-07	-.2557E-09	.3995E-12
50.	10.	110.	152.41	-.1272E-04	.7427E-07	-.2657E-09	.4034E-12
50.	1C.	120.	119.18	-.1371E-04	.7809E-07	-.2745E-09	.4C53E-12
50.	10.	130.	100.86	-.1478E-04	.8210E-07	-.2839E-09	.4109E-12
50.	10.	140.	89.25	-.1590E-04	.8654E-07	-.2951E-09	.4189E-12
50.	15.	80.	-450.35	-.6183E-05	.1050E-07	-.1884E-10	.1232E-13
50.	15.	90.	612.28	-.5422E-05	.1286E-07	-.2114E-10	.1519E-13
50.	15.	100.	218.33	-.5318E-05	.1381E-07	-.2179E-10	.1474E-13
50.	15.	110.	144.79	-.5542E-05	.1437E-07	-.2189E-10	.1397E-13
50.	15.	120.	113.76	-.5925E-05	.1453E-07	-.2180E-10	.1323E-13
50.	15.	130.	96.66	-.6395E-05	.1530E-07	-.2174E-10	.1263E-13
50.	15.	140.	85.82	-.6902E-05	.1583E-07	-.2180E-10	.1218E-13
50.	20.	90.	571.46	-.3286E-05	.3982E-08	-.3868E-11	.1534E-14
50.	20.	100.	205.49	-.2994E-05	.4354E-08	-.3761E-11	.1386E-14
50.	20.	110.	137.17	-.3021E-05	.4400E-08	-.3538E-11	.1173E-14
50.	20.	120.	108.35	-.3204E-05	.4368E-08	-.3286E-11	.9957E-15
50.	20.	130.	92.45	-.3461E-05	.4332E-08	-.3055E-11	.8545E-15
50.	20.	140.	82.38	-.3749E-05	.4313E-08	-.2863E-11	.7455E-15
50.	25.	90.	530.64	-.2257E-05	.1461E-08	-.8916E-12	.1145E-15
50.	25.	100.	192.64	-.1892E-05	.1766E-08	-.9324E-12	.2100E-15
50.	25.	110.	129.54	-.1822E-05	.1666E-08	-.7628E-12	.1411E-15
50.	25.	120.	102.93	-.1889E-05	.1485E-08	-.5893E-12	.9079E-16
50.	25.	130.	88.25	-.2003E-05	.1280E-08	-.4300E-12	.5433E-16

第 4 表

θ_c (deg)	X_1 (mm)	X_2 (mm)	R_{m2} (mm)	B_2 (mm^{-4})	C_2 (mm^{-6})	D_2 (mm^{-8})	E_2 (mm^{-10})
40.	5.	20.	-18.85	-.1826E-04	-.1301E-06	.8269E-09	-.6194E-11
40.	5.	30.	-31.09	-.5063E-05	-.4522E-08	.1221E-11	-.2669E-13
40.	5.	40.	-45.43	-.2096E-05	-.1671E-09	-.9523E-12	.1752E-15
40.	5.	50.	-59.59	-.1100E-05	.1544E-09	-.3780E-12	.2189E-15
40.	5.	60.	-74.57	-.6708E-06	.1355E-09	-.1554E-12	.7666E-16
40.	5.	70.	-90.60	-.4539E-06	.9561E-10	-.7063E-13	.2751E-16
40.	5.	00.	-100.09	-.3322E-06	.6664E-10	-.3528E-13	.1082E-16
40.	5.	90.	-127.62	-.2588E-06	.4782E-10	-.1916E-13	.4669E-17
40.	8.	100.	-150.16	-.2126E-06	.3570E-10	-.1119E-13	.2189E-17
40.	10.	30.	-27.65	-.5479E-05	-.3710E-07	.1493E-09	-.3854E-12
40.	10.	40.	-42.49	-.2371E-05	-.1634E-08	.1122E-11	-.3783E-14
40.	10.	50.	-58.27	-.1150E-05	-.8135E-10	-.1428E-12	-.4091E-16
40.	10.	60.	-75.29	-.6620E-06	.8637E-10	-.9524E-13	.3717E-16
40.	10.	70.	-94.00	-.4316E-06	.8983E-10	-.5239E-13	.1932E-16
40.	10.	00.	-115.10	-.3089E-06	.7207E-10	-.2985E-13	.8996E-17
40.	10.	90.	-139.73	-.2380E-06	.5570E-10	-.1797E-13	.4344E-17
40.	10.	100.	-169.89	-.1951E-06	.4349E-10	-.1140E-13	.2214E-17
40.	15.	40.	-38.95	-.2407E-05	-.7989E-08	.1754E-10	-.2531E-13
40.	15.	50.	-56.64	-.1242E-05	-.3749E-09	.1188E-12	-.3536E-15
40.	15.	60.	-76.19	-.6586E-06	.5027E-10	-.6141E-13	.1497E-16
40.	15.	70.	-90.36	-.4031E-06	.9060E-10	-.4025E-13	.1465E-16
40.	15.	00.	-124.42	-.2767E-06	.0032E-10	-.2550E-13	.7715E-17
40.	15.	90.	-156.58	-.2085E-06	.6488E-10	-.1681E-13	.4035E-17
40.	15.	100.	-199.12	-.1697E-06	.5199E-10	-.1154E-13	.2203E-17
40.	20.	50.	-54.61	-.1343E-05	-.1190E-08	.1281E-11	-.1389E-14
40.	20.	60.	-77.35	-.6591E-06	.1933E-10	-.3019E-13	-.1324E-17
40.	20.	70.	-104.17	-.3639E-06	.9021E-10	-.3187E-13	.1227E-16
40.	20.	80.	-137.40	-.2315E-06	.9104E-10	-.2170E-13	.6794E-17
40.	20.	90.	-101.60	-.1669E-06	.7572E-10	-.1569E-13	.3753E-17
40.	20.	100.	-246.91	-.1342E-06	.6142E-10	-.1167E-13	.2177E-17
40.	25.	50.	-52.00	-.7213E-06	-.7502E-08	.1263E-10	-.9021E-14
40.	25.	60.	-70.09	-.6605E-06	-.1603E-10	-.1064E-13	-.2021E-16
40.	25.	70.	-112.26	-.3069E-06	.1144E-09	-.2557E-13	.1162E-16
40.	25.	80.	-156.72	-.1673E-06	.1070E-09	-.1026E-13	.6213E-17
40.	25.	90.	-222.66	-.1090E-06	.8902E-10	-.1476E-13	.3579E-17
40.	25.	100.	-339.18	-.0546E-07	.7226E-10	-.1199E-13	.2206E-17
40.	30.	60.	-81.04	-.6520E-06	-.0050E-10	.5401E-13	-.8500E-16
40.	30.	70.	-124.33	-.2199E-06	.1439E-09	-.2079E-13	.1293E-16
40.	30.	80.	-100.54	-.7494E-07	.1322E-09	-.1652E-13	.6526E-17
40.	30.	90.	-302.43	-.2075E-07	.1076E-09	-.1642E-13	.3964E-17
40.	30.	100.	-592.05	-.1962E-07	.0633E-10	-.1330E-13	.2549E-17
40.	35.	60.	-84.26	-.5945E-06	-.2022E-09	.2034E-12	-.1535E-15
40.	35.	70.	-144.28	-.0660E-07	.2160E-09	-.3430E-13	.2254E-16
40.	35.	00.	-250.75	.5027E-07	.1962E-09	-.3773E-13	.1361E-16
40.	35.	90.	-524.49	.7406E-07	.1526E-09	-.3102E-13	.8167E-17
40.	35.	100.	-4234.79	.6313E-07	.1156E-09	-.2272E-13	.4742E-17
40.	40.	60.	-09.61	-.2380E-06	-.1303E-00	.1303E-11	-.5235E-15

第 5 表

θ_c (deg)	X_1 (mm)	X_2 (mm)	R_{m2} (mm)	B_2 (mm^{-4})	C_2 (mm^{-6})	D_2 (mm^{-8})	E_2 (mm^{-10})
45.	5.	20.	-14.07	.6357E-04	-.3260E-05	.3948E-07	-.1646E-09
45.	5.	30.	-23.36	-.2273E-05	-.3124E-07	.1357E-09	-.3420E-12
45.	5.	40.	-32.57	-.1112E-05	-.2947E-08	.4989E-11	-.8244E-14
45.	5.	50.	-41.69	-.5372E-06	-.6130E-09	.5444E-12	-.4954E-15
45.	5.	60.	-50.68	-.2924E-06	-.1802E-09	.1115E-12	-.4342E-16
45.	5.	70.	-59.54	-.1751E-06	-.6336E-10	.3318E-13	-.9462E-18
45.	5.	80.	-68.22	-.1126E-06	-.2445E-10	.1252E-13	.1923E-17
45.	5.	90.	-76.68	-.7626E-07	-.9580E-11	.5536E-14	.1365E-17
45.	5.	100.	-84.88	-.5348E-07	-.3366E-11	.2766E-14	.7942E-18
45.	5.	110.	-92.71	-.3815E-07	-.6002E-12	.1528E-14	.4528E-18
45.	10.	40.	-29.70	.1136E-05	-.3265E-07	.9591E-10	-.1093E-12
45.	10.	50.	-39.57	-.5297E-06	-.2037E-08	.3056E-11	-.2803E-14
45.	10.	60.	-49.42	-.3236E-06	-.3281E-09	.2409E-12	-.1645E-15
45.	10.	70.	-59.25	-.1831E-06	-.7903E-10	.3594E-13	-.9653E-17
45.	10.	80.	-69.06	-.1079E-06	-.1997E-10	.9487E-14	.1953E-17
45.	10.	90.	-78.83	-.6633E-07	-.2334E-11	.3803E-14	.1858E-17
45.	10.	100.	-88.55	-.4216E-07	.3372E-11	.1919E-14	.1112E-17
45.	10.	110.	-98.21	-.2731E-07	.5092E-11	.1094E-14	.6308E-18
45.	15.	50.	-37.14	.1865E-05	-.1930E-07	.3659E-10	-.2502E-13
45.	15.	60.	-47.96	-.2737E-06	-.9945E-09	.1093E-11	-.6490E-15
45.	15.	70.	-58.92	-.1917E-06	-.1213E-09	.6499E-13	-.2907E-16
45.	15.	80.	-70.05	-.1026E-06	-.1532E-10	.6793E-14	.1979E-17
45.	15.	90.	-81.40	-.5252E-07	.5975E-11	.2324E-14	.2345E-17
45.	15.	100.	-93.05	-.2504E-07	.1088E-10	.1513E-14	.1352E-17
45.	15.	110.	-105.10	-.9581E-08	.1144E-10	.1019E-14	.7443E-18
45.	20.	70.	-58.52	-.1805E-06	-.2663E-09	.1940E-12	-.8425E-16
45.	20.	80.	-71.24	-.9604E-07	-.1008E-10	.4326E-14	.2071E-17
45.	20.	90.	-84.56	-.3312E-07	.1604E-10	.1021E-14	.2888E-17
45.	20.	100.	-98.69	-.1171E-09	.1962E-10	.1499E-14	.1545E-17
45.	20.	110.	-113.98	.1690E-07	.1902E-10	.1119E-14	.8347E-18
45.	25.	70.	-58.05	-.1395E-07	-.9389E-09	.8164E-12	-.2944E-15
45.	25.	80.	-72.71	-.8724E-07	-.2611E-11	.1252E-14	.2535E-17
45.	25.	90.	-88.52	-.5779E-08	.2916E-10	-.3564E-15	.3601E-17
45.	25.	100.	-105.97	.3482E-07	.3134E-10	.1219E-14	.1845E-17
45.	25.	110.	-125.88	.5374E-07	.3003E-10	.4363E-15	.1079E-17
45.	30.	80.	-74.55	-.7585E-07	.1272E-10	-.5691E-14	.4323E-17
45.	30.	90.	-93.63	.3123E-07	.5081E-10	-.4172E-14	.5030E-17
45.	30.	100.	-115.73	.7779E-07	.5716E-10	-.4743E-14	.3221E-17
45.	30.	110.	-142.61	.9582E-07	.5853E-10	-.7487E-14	.2500E-17
45.	35.	80.	-76.92	-.6806E-07	.5939E-10	-.3033E-13	.1073E-16
45.	35.	90.	-100.50	.1824E-07	.1947E-09	-.6846E-13	.1688E-16
45.	40.	80.	-80.12	-.1658E-06	.3407E-09	-.1844E-12	.4259E-16

第 6 表

θ_c (deg)	X_1 (mm)	X_2 (mm)	R_{m2} (mm)	B_2 (mm^{-4})	C_2 (mm^{-6})	D_2 (mm^{-8})	E_2 (mm^{-10})
50.	5.	40.	-26.56	.9049E-06	-.1601E-07	.4907E-10	-.5673E-13
50.	5.	50.	-33.61	.2956E-07	-.1306E-08	.2200E-11	-.1628E-14
50.	5.	60.	-40.34	.1704E-07	-.9986E-10	.1127E-13	.8408E-16
50.	5.	70.	-46.72	.4423E-07	.5013E-10	-.8986E-13	.8317E-16
50.	5.	80.	-52.68	.6317E-07	.6536E-10	-.6295E-13	.4259E-16
50.	5.	90.	-58.13	.7582E-07	.6124E-10	-.4148E-13	.2221E-16
50.	5.	100.	-62.97	.8609E-07	.5674E-10	-.2977E-13	.1279E-16
50.	5.	110.	-67.09	.9646E-07	.5613E-10	-.2453E-13	.8416E-17
50.	5.	120.	-70.31	.1077E-06	.6254E-10	-.2437E-13	.6571E-17
50.	5.	130.	-72.40	.1163E-06	.8557E-10	-.3160E-13	.6557E-17
50.	5.	140.	-73.07	.8590E-07	.1770E-09	-.6410E-13	.9997E-17
50.	10.	60.	-38.77	.5343E-06	-.2916E-08	.4056E-11	-.1964E-14
50.	10.	70.	-45.73	.5091E-07	-.3623E-10	.7146E-13	-.9669E-17
50.	10.	80.	-52.31	.3739E-07	.1027E-09	-.9511E-13	.4346E-16
50.	10.	90.	-58.44	.5786E-07	.9359E-10	-.6274E-13	.2466E-16
50.	10.	100.	-64.03	.7556E-07	.7326E-10	-.3756E-13	.1323E-16
50.	10.	110.	-68.93	.9023E-07	.5987E-10	-.2447E-13	.7697E-17
50.	10.	120.	-72.99	.1046E-06	.5370E-10	-.1850E-13	.5069E-17
50.	10.	130.	-75.97	.1209E-06	.5547E-10	-.1732E-13	.3967E-17
50.	10.	140.	-77.56	.1369E-06	.7348E-10	-.2262E-13	.4084E-17
50.	15.	80.	-51.90	.5131E-07	.3348E-11	-.8650E-14	.9796E-17
50.	15.	90.	-58.81	.3347E-07	.1293E-09	-.8331E-13	.2606E-16
50.	15.	100.	-65.24	.6396E-07	.9118E-10	-.4484E-13	.1344E-16
50.	15.	110.	-71.08	.8752E-07	.6278E-10	-.2342E-13	.6924E-17
50.	15.	120.	-76.17	.1061E-06	.4704E-10	-.1356E-13	.3931E-17
50.	15.	130.	-80.28	.1246E-06	.3907E-10	-.9202E-14	.2526E-17
50.	15.	140.	-83.08	.1481E-06	.3690E-10	-.7910E-14	.1912E-17
50.	20.	90.	-59.23	.1602E-07	.1381E-09	-.8321E-13	.2229E-16
50.	20.	100.	-66.67	.5076E-07	.1123E-09	-.5235E-13	.1360E-16
50.	20.	110.	-73.64	.8910E-07	.6598E-10	-.2189E-13	.6225E-17
50.	20.	120.	-80.01	.1124E-06	.4406E-10	-.9923E-14	.3174E-17
50.	20.	130.	-85.56	.1304E-06	.3367E-10	-.5328E-14	.1850E-17
50.	20.	140.	-90.01	.1505E-06	.2811E-10	-.3443E-14	.1212E-17
50.	25.	90.	-59.73	.1219E-06	-.9607E-10	.5991E-13	-.8371E-17
50.	25.	100.	-68.37	.3349E-07	.1417E-09	-.6211E-13	.1410E-16
50.	25.	110.	-76.73	.9355E-07	.7427E-10	-.2182E-13	.5902E-17
50.	25.	120.	-84.72	.1169E-06	.5610E-10	-.1168E-13	.3268E-17
50.	25.	130.	-92.22	.1258E-06	.5542E-10	-.1077E-13	.2405E-17

第 7 表

θ_c (deg)	X_1 (mm)	X_2 (mm)	R_s° (mm)	A_s (mm^{-2})	B_s (mm^{-4})	C_s (mm^{-6})	D_s (mm^{-8})	E_s (mm^{-10})
40.	5.	20.	6.77	.1427E-02	-.7923E-06	.7048E-07	-.3924E-09	.2300E-11
40.	5.	30.	9.40	.1493E-02	-.8558E-06	.4591E-08	-.3232E-11	.9555E-14
40.	5.	40.	11.78	.1410E-02	-.5626E-06	.1115E-08	-.2771E-12	.3216E-15
40.	5.	50.	13.89	.1330E-02	-.3713E-06	.4146E-09	-.8179E-13	.4625E-16
40.	5.	60.	15.72	.1259E-02	-.2593E-06	.1919E-09	-.3302E-13	.1319E-16
40.	5.	70.	17.25	.1225E-02	-.1910E-06	.1033E-09	-.1645E-13	.4972E-17
40.	5.	80.	18.46	.1193E-02	-.1470E-06	.6180E-10	-.9095E-14	.2124E-17
40.	5.	90.	19.34	.1169E-02	-.1174E-06	.4025E-10	-.5496E-14	.1008E-17
40.	5.	100.	19.87	.1150E-02	-.9678E-07	.2811E-10	-.3588E-14	.5262E-18
40.	10.	30.	10.02	.1285E-02	-.9485E-06	.2584E-07	-.9307E-10	.1957E-12
40.	10.	40.	12.35	.1386E-02	-.3088E-06	.1477E-08	-.1055E-11	.1665E-14
40.	10.	50.	14.41	.1394E-02	-.2787E-06	.4222E-09	-.9516E-13	.5519E-16
40.	10.	60.	16.18	.1369E-02	-.2220E-06	.1928E-09	-.3066E-13	.6643E-17
40.	10.	70.	17.66	.1339E-02	-.1765E-06	.1072E-09	-.1570E-13	.3096E-17
40.	10.	80.	18.83	.1312E-02	-.1434E-06	.6671E-10	-.9273E-14	.1807E-17
40.	10.	90.	19.66	.1289E-02	-.1194E-06	.4489E-10	-.5863E-14	.1048E-17
40.	10.	100.	20.15	.1269E-02	-.1021E-06	.3242E-10	-.4058E-14	.6308E-18
40.	15.	40.	12.91	.1338E-02	-.6332E-06	.6882E-08	-.1400E-10	.1602E-13
40.	15.	50.	14.92	.1424E-02	-.2170E-06	.5187E-09	-.2350E-12	.2027E-15
40.	15.	60.	16.64	.1454E-02	-.2002E-06	.1915E-09	-.3441E-13	.6454E-17
40.	15.	70.	18.07	.1451E-02	-.1690E-06	.1085E-09	-.1678E-13	.2189E-17
40.	15.	80.	19.29	.1437E-02	-.1420E-06	.7122E-10	-.1038E-13	.1840E-17
40.	15.	90.	19.98	.1421E-02	-.1213E-06	.5054E-10	-.6933E-14	.1310E-17
40.	15.	100.	20.42	.1404E-02	-.1058E-06	.3787E-10	-.4845E-14	.8578E-18
40.	20.	50.	15.42	.1437E-02	-.2912E-06	.1290E-08	-.1400E-11	.1053E-14
40.	20.	60.	17.09	.1529E-02	-.1888E-06	.1915E-09	-.4091E-13	.1034E-16
40.	20.	70.	18.48	.1566E-02	-.1667E-06	.1102E-09	-.1990E-13	.2495E-17
40.	20.	80.	19.55	.1574E-02	-.1414E-06	.7890E-10	-.1388E-13	.2936E-17
40.	20.	90.	20.29	.1570E-02	-.1212E-06	.5972E-10	-.9564E-14	.2213E-17
40.	20.	100.	20.69	.1562E-02	-.1061E-06	.4656E-10	-.6642E-14	.1451E-17
40.	25.	50.	15.91	.1625E-02	-.2795E-05	.1190E-07	-.1748E-10	.1019E-13
40.	25.	60.	17.54	.1598E-02	-.1907E-06	.2080E-09	-.6434E-13	.2293E-16
40.	25.	70.	18.87	.1690E-02	-.1677E-06	.1180E-09	-.2821E-13	.5333E-17
40.	25.	80.	19.90	.1730E-02	-.1412E-06	.9901E-10	-.2477E-13	.6952E-17
40.	25.	90.	20.59	.1745E-02	-.1185E-06	.8048E-10	-.1752E-13	.4957E-17
40.	25.	100.	20.95	.1750E-02	-.1016E-06	.6442E-10	-.1167E-13	.3042E-17
40.	30.	60.	17.97	.1669E-02	-.2281E-06	.2999E-09	-.1647E-12	.6499E-16
40.	30.	70.	19.26	.1835E-02	-.1852E-06	.1757E-09	-.7488E-13	.2185E-16
40.	30.	80.	20.24	.1920E-02	-.1609E-06	.1846E-09	-.7627E-13	.2337E-16
40.	30.	90.	20.89	.1961E-02	-.1291E-06	.1527E-09	-.5221E-13	.1484E-16
40.	30.	100.	21.21	.1984E-02	-.1014E-06	.1159E-09	-.3137E-13	.8144E-17
40.	35.	60.	18.40	.1772E-02	-.4826E-06	.8876E-09	-.7256E-12	.2553E-15
40.	35.	70.	19.64	.2076E-02	-.5608E-06	.9526E-09	-.6396E-12	.1799E-15
40.	35.	80.	20.58	.2256E-02	-.6622E-06	.1094E-08	-.6251E-12	.1530E-15
40.	35.	90.	21.19	.2313E-02	-.4842E-06	.7605E-09	-.3696E-12	.8147E-16
40.	35.	100.	21.46	.2326E-02	-.2843E-06	.4418E-09	-.1791E-12	.3652E-16
40.	40.	60.	18.82	.2292E-02	-.3520E-05	.7349E-08	-.6105E-11	.1782E-14

第 8 表

θ_c (deg)	X_1 (mm)	X_2 (mm)	R_s° (mm)	A_s (mm^{-2})	B_s (mm^{-4})	C_s (mm^{-6})	D_s (mm^{-8})	E_s (mm^{-10})
45.	5.	20.	5.77	.1901E-02	-.5675E-04	.1795E-05	-.1744E-07	.6378E-10
45.	5.	30.	9.40	.7137E-03	.9348E-06	.1485E-07	-.5335E-10	.1210E-12
45.	5.	40.	11.78	.6251E-03	.4914E-06	.1254E-08	-.1519E-11	.2768E-14
45.	5.	50.	13.89	.6213E-03	.2222E-06	.2525E-09	-.1134E-12	.1857E-15
45.	5.	60.	15.72	.6370E-03	.1133E-06	.8519E-10	-.2055E-13	.2597E-16
45.	5.	70.	17.25	.6639E-03	.6421E-07	.3549E-10	-.8136E-14	.6197E-17
45.	5.	80.	18.45	.6977E-03	.3990E-07	.1695E-10	-.4274E-14	.2016E-17
45.	5.	90.	19.34	.7368E-03	.2581E-07	.8761E-11	-.2447E-14	.7846E-18
45.	5.	100.	19.87	.7809E-03	.1915E-07	.4750E-11	-.1479E-14	.3453E-18
45.	5.	110.	20.03	.8302E-03	.1438E-07	.2577E-11	-.9239E-15	.1663E-18
45.	10.	40.	12.35	.1116E-02	-.1826E-05	.2175E-07	-.5230E-10	.5197E-13
45.	10.	50.	14.41	.8545E-03	.2711E-06	.1208E-08	-.1527E-11	.1270E-14
45.	10.	60.	16.18	.7968E-03	.1946E-06	.1738E-09	-.8037E-13	.6920E-16
45.	10.	70.	17.66	.7849E-03	.1128E-06	.4434E-10	-.6221E-15	.4673E-17
45.	10.	80.	18.83	.7893E-03	.6673E-07	.1715E-10	.1395E-14	.4482E-18
45.	10.	90.	19.66	.8044E-03	.4089E-07	.9030E-11	-.3128E-15	.3165E-18
45.	10.	100.	20.15	.8271E-03	.2564E-07	.5876E-11	-.1106E-14	.3223E-18
45.	10.	110.	20.25	.8554E-03	.1535E-07	.4221E-11	-.1247E-14	.2698E-18
45.	15.	50.	14.92	.1372E-02	-.3121E-05	.1653E-07	-.2559E-10	.1516E-13
45.	15.	60.	16.64	.9692E-03	.1150E-06	.7585E-09	-.7179E-12	.3743E-15
45.	15.	70.	18.07	.8970E-03	.1425E-06	.7890E-10	-.2294E-13	.1450E-16
45.	15.	80.	19.29	.8727E-03	.8756E-07	.1527E-10	.5202E-14	-.8761E-18
45.	15.	90.	19.98	.8568E-03	.5122E-07	.7720E-11	.1381E-14	-.2704E-18
45.	15.	100.	20.42	.8710E-03	.2923E-07	.7306E-11	-.1420E-14	.3479E-18
45.	15.	110.	20.49	.8816E-03	.1565E-07	.7566E-11	-.2482E-14	.5126E-18
45.	20.	70.	18.48	.1010E-02	.1098E-06	.2439E-09	-.1541E-12	.5944E-16
45.	20.	80.	19.55	.9487E-03	.1027E-06	.1304E-10	.6939E-14	-.1581E-17
45.	20.	90.	20.29	.9248E-03	.5594E-07	.8474E-11	.6010E-15	-.3738E-18
45.	20.	100.	20.69	.9150E-03	.2557E-07	.1554E-10	-.5591E-14	.1092E-17
45.	20.	110.	20.71	.9119E-03	.6775E-08	.2009E-10	-.7794E-14	.1461E-17
45.	25.	70.	18.87	.1185E-02	-.3479E-06	.1252E-08	-.9280E-12	.2810E-15
45.	25.	80.	19.90	.1017E-02	.1138E-06	.8559E-11	.8587E-14	-.2183E-17
45.	25.	90.	20.59	.9815E-03	.4574E-07	.2441E-10	-.9283E-14	.1311E-17
45.	25.	100.	20.95	.9665E-03	-.8241E-08	.5874E-10	-.2627E-13	.4718E-17
45.	25.	110.	20.94	.9587E-03	-.4221E-07	.7704E-10	-.3126E-13	.5249E-17
45.	30.	80.	20.24	.1078E-02	.1266E-06	-.6671E-11	.1534E-13	-.3922E-17
45.	30.	90.	20.89	.1061E-02	-.7131E-07	.1683E-09	-.8153E-13	.1371E-16
45.	30.	100.	21.21	.1100E-02	-.3200E-06	.4003E-09	-.1737E-12	.2732E-16
45.	30.	110.	21.15	.1151E-02	-.5231E-06	.5560E-09	-.2131E-12	.3013E-16
45.	35.	80.	20.58	.1127E-02	.1559E-06	-.5323E-10	.3778E-13	-.9032E-17
45.	35.	90.	21.19	-.1481E-02	.7829E-05	-.7082E-08	.2451E-11	-.2787E-15
45.	40.	80.	20.91	.3000E-03	.2579E-05	-.2011E-08	.5893E-12	-.5341E-16

第 9 表

θ_e (deg)	X_1 (mm)	X_2 (mm)	R_s° (mm)	A_s (mm^{-2})	B_s (mm^{-4})	C_s (mm^{-6})	D_s (mm^{-8})	E_s (mm^{-10})
50.	5.	40.	11.78	.1001E-02	-.4910E-06	.1106E-07	-.2735E-10	.2966E-13
50.	5.	50.	13.89	.8443E-03	.1708E-06	.1301E-08	-.1943E-11	.1614E-14
50.	5.	60.	15.72	.8205E-03	.1327E-06	.2618E-09	-.2507E-12	.1687E-15
50.	5.	70.	17.25	.8476E-03	.7823E-07	.7052E-10	-.4750E-13	.2576E-16
50.	5.	80.	18.46	.9030E-03	.4273E-07	.2123E-10	-.1145E-13	.4692E-17
50.	5.	90.	19.34	.9793E-03	.1986E-07	.5493E-11	-.2882E-14	.7209E-18
50.	5.	100.	19.87	.1075E-02	.3468E-08	-.8923E-13	-.3965E-15	-.1014E-18
50.	5.	110.	20.03	.1193E-02	-.1043E-07	-.1962E-11	.3979E-15	-.2431E-18
50.	5.	120.	19.79	.1338E-02	-.2482E-07	-.2111E-11	.6135E-15	-.2294E-18
50.	5.	130.	19.14	.1520E-02	-.4304E-07	-.9465E-12	.5524E-15	-.1832E-18
50.	10.	60.	16.18	.1266E-02	-.6194E-06	.3208E-08	-.3602E-11	.1639E-14
50.	10.	70.	17.66	.1104E-02	.3049E-07	.4471E-09	-.3544E-12	.1411E-15
50.	10.	80.	18.83	.1069E-02	.7299E-07	.7966E-10	-.4035E-13	.1606E-16
50.	10.	90.	19.66	.1085E-02	.5038E-07	.1224E-10	-.1300E-14	.1481E-17
50.	10.	100.	20.15	.1134E-02	.2485E-07	-.1129E-11	.2449E-14	-.2424E-18
50.	10.	110.	20.26	.1211E-02	.3290E-08	-.2859E-11	.1638E-14	-.2864E-18
50.	10.	120.	19.98	.1315E-02	-.1589E-07	-.1784E-11	.6571E-15	-.1667E-18
50.	10.	130.	19.29	.1453E-02	-.3561E-07	.1504E-12	-.1540E-16	-.7782E-19
50.	10.	140.	18.16	.1636E-02	-.6007E-07	.2979E-11	-.5174E-15	-.2141E-19
50.	15.	80.	19.19	.1261E-02	-.6448E-07	.4174E-09	-.2566E-12	.7086E-16
50.	15.	90.	19.98	.1187E-02	.6379E-07	.3723E-10	-.1145E-13	.4134E-17
50.	15.	100.	20.42	.1185E-02	.4812E-07	-.9673E-11	.8122E-14	-.1163E-17
50.	15.	110.	20.49	.1220E-02	.1854E-07	-.9731E-11	.5070E-14	-.8295E-18
50.	15.	120.	20.17	.1286E-02	-.9317E-08	-.7941E-11	.1135E-14	-.2525E-18
50.	15.	130.	19.44	.1382E-02	-.3554E-07	.6002E-11	-.1523E-14	.9325E-19
50.	15.	140.	18.28	.1516E-02	-.6318E-07	.1037E-10	-.3176E-14	.2684E-18
50.	20.	90.	20.29	.1300E-02	.2269E-09	.1577E-09	-.7091E-13	.1554E-16
50.	20.	100.	20.69	.1225E-02	.7208E-07	-.2290E-10	.1456E-13	-.2264E-17
50.	20.	110.	20.71	.1223E-02	.2694E-07	-.1355E-10	.6638E-14	-.1194E-17
50.	20.	120.	20.36	.1258E-02	-.2841E-07	.1499E-10	-.5207E-14	.4347E-18
50.	20.	130.	19.59	.1326E-02	-.8419E-07	.4324E-10	-.1406E-13	.1444E-17
50.	20.	140.	18.40	.1426E-02	-.1405E-06	.6817E-10	-.2006E-13	.1949E-17
50.	25.	90.	20.59	.1516E-02	-.4924E-06	.7795E-09	-.3606E-12	.6349E-16
50.	25.	100.	20.95	.1253E-02	.1051E-06	-.4901E-10	.2480E-13	-.3901E-17
50.	25.	110.	20.94	.1244E-02	-.4371E-07	.4881E-10	-.1539E-13	.1226E-17
50.	25.	120.	20.54	.1356E-02	-.3859E-06	.2967E-09	-.9307E-13	.9765E-17
50.	25.	130.	19.74	.1700E-02	-.1144E-05	.8008E-09	-.2263E-12	.2187E-16

第13図に本発明に基づくレンズ形状の一実施例を用いたレーザービームプリンタの光学系の全体像を表す斜視図を示す。半導体レーザー2から出射した光束はコリメータレンズ3で平行光束となり、シリンドリカルレンズ4によつて球欠方向にのみ収束させられて回転多面鏡偏向器6の鏡面付近で線状結像する。光束は多面鏡5の回転によつて子午平面内で等角速度偏向され、本発明による走査用レンズ1を通過した後、感光ドラム7上に結像する。球欠方向については鏡面と感光ドラム面が共役結像点となつており面倒れ補正系をなしている。像点は本発明の走査用レンズ1によつて感光ドラム7の軸方向に等速走査され、像面歪曲なく直線上に結像する。この走査1回につき感光ドラムが1ピッチだけ回転してそれが繰返されることによつて感光ドラム上に潜像が形成される。

〔効果〕

以上述べてきたように、本発明の光走査装置は走査用レンズが、光束が被走査平面上で等速で移動するような歪み特性を有し、かつ被走査平面上における光束の像面湾曲収差が零またはほとんど零となる如く両面が非球面である単玉レンズであるため、単玉であつてもほとんど収差がなくきわめて良好な結像スポットが得られまた広角偏向で光軸長の短い走査用レンズが構成できる。また同じ理由によりレンズ硝材が低屈折率であつても設計上の何らの支障にならず、従つてレンズ硝材のプラスチック化が可能となる。従つて小型で低価格、しかも高性能な光走査装置を提供することができる。という効果を有する。

4. 図面の簡単な説明

第1図は本発明の光走査装置の概その構成を示す原理図、第2図は本発明のレンズ形状を構成する原理を説明するための原理図、第3図は本発明の走査用レンズが単玉両非球面レンズで実現可能であることを説明するための原理図、第4図は本発明の走査用レンズの形状を算出する方法を説明するための原理図、第5図から第12図までは本発明のレンズ形状の実施例をそれぞれ示した図、第13図は本発明の光走査装置全体の実施例を示す斜視図である。

図中

1…走査用レンズ　2…半導体レーザー

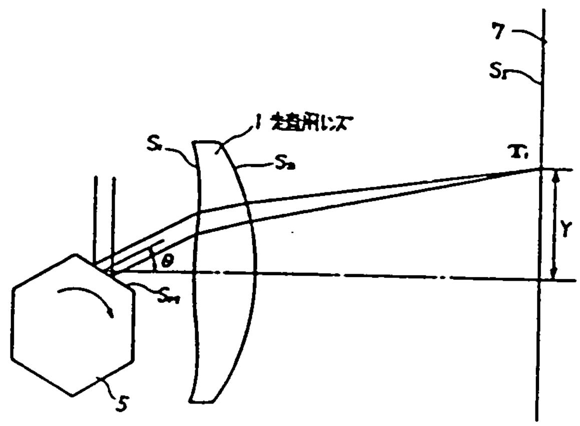
5…多面鏡　6…回転多面鏡偏向器

7…被走査面（感光ドラム）

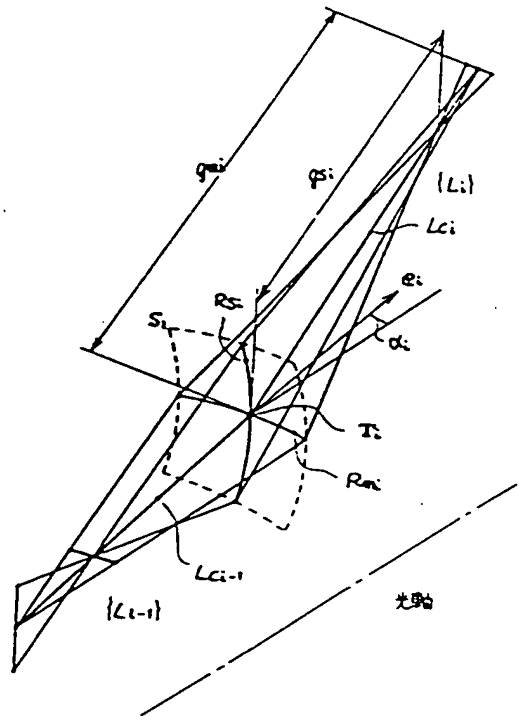
以上

出願人　セイコーエプソン株式会社

代理人　弁理士 最上務（他1名）



第1図



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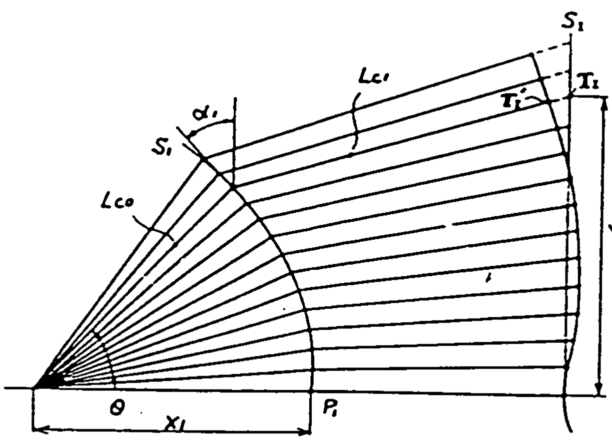
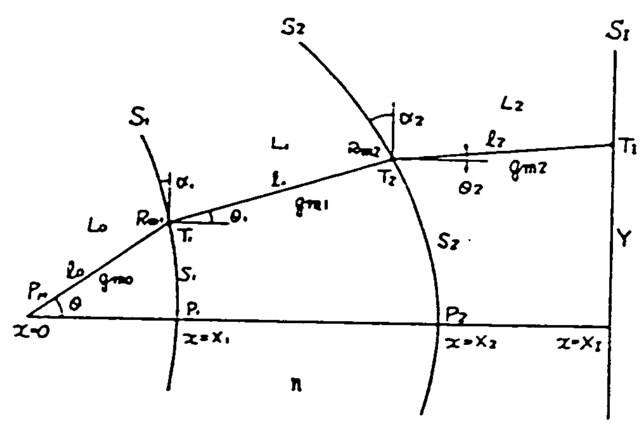
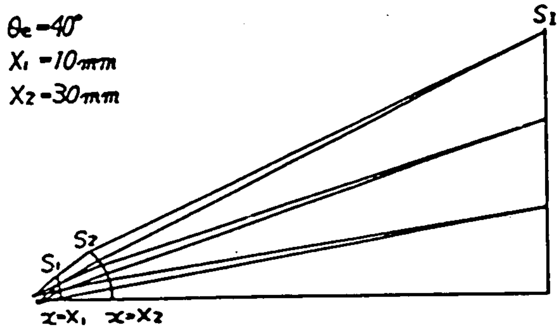


第3図



第4図



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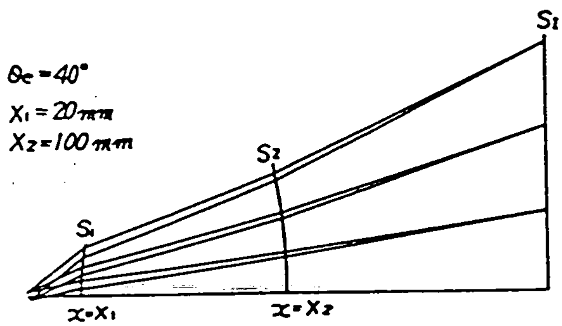

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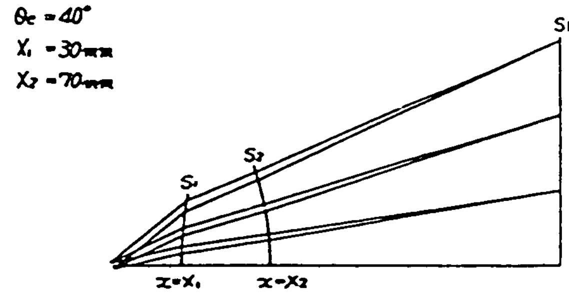

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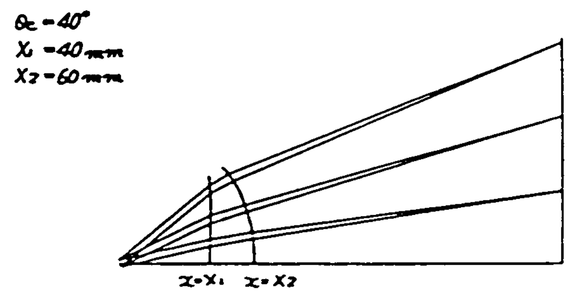

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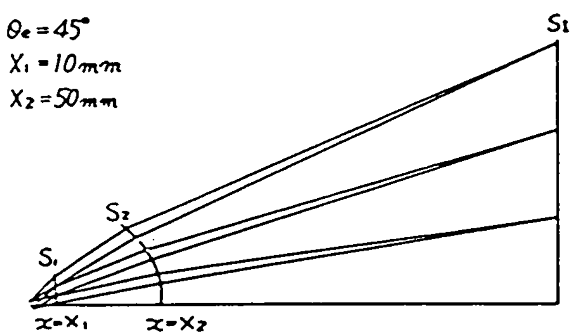

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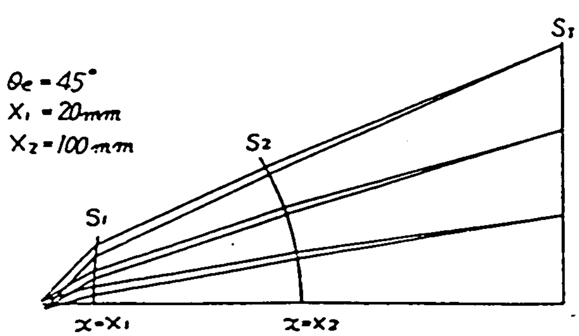

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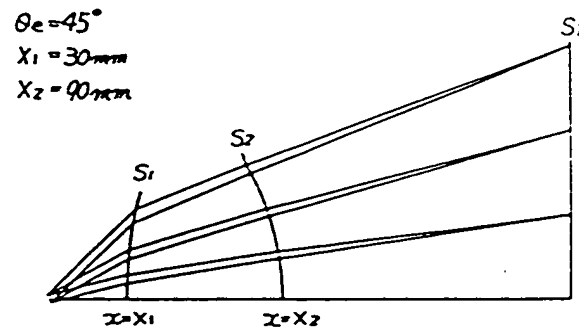

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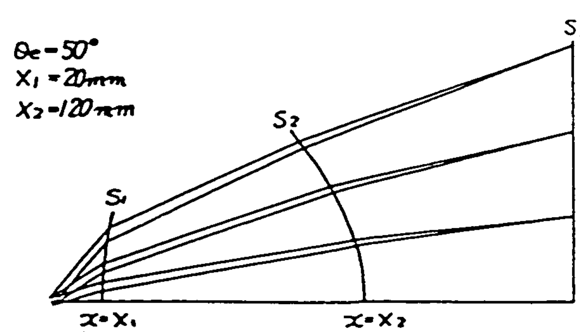

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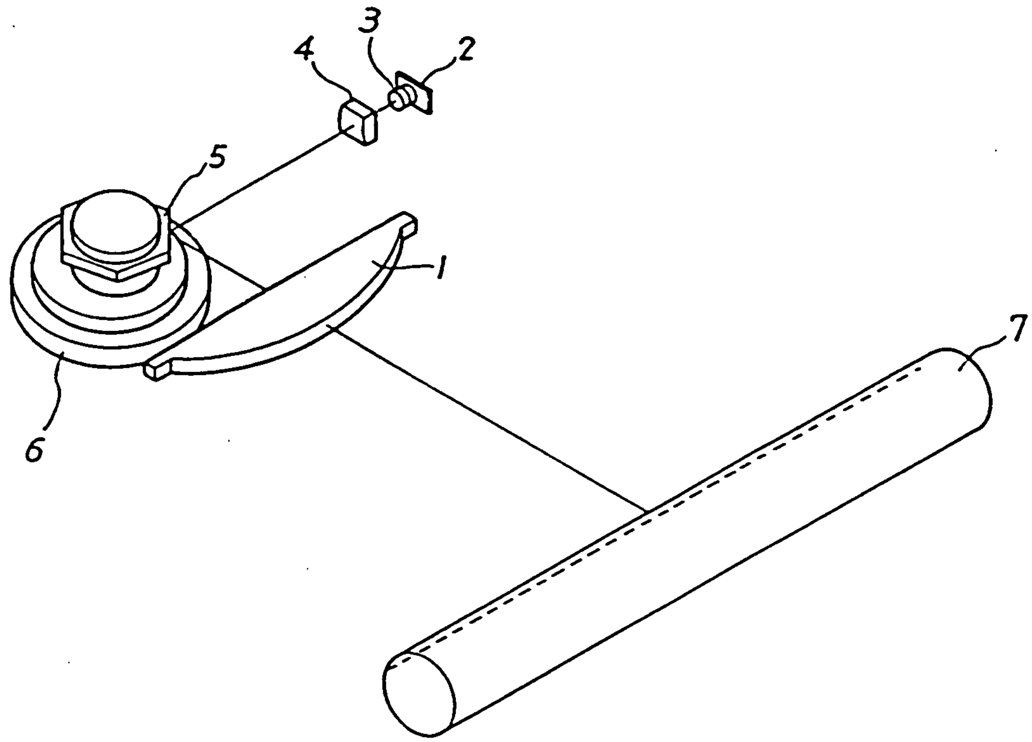

第13図

Japanese Unexamined Patent Publication No. 62-139520
Publication Date: June 23, 1987
Application No. 60-280246
Application Date: December 13, 1985
Applicant: Seiko Epson Corporation
Inventor: Suzuki
Agents: Mogami, Patent Attorney, and one other

SPECIFICATION

1. Title of the Invention OPTICAL SCANNING DEVICE

2. Claims

(1) An optical scanning device comprising a light source for emitting a thin light beam, a deflector for deflecting the light beam in a predetermined direction in order to perform scanning, and a scanning lens for forming the light beam deflected by the deflector into an image on a scanning plane surface, wherein the scanning lens is a single lens which has a strain characteristic allowing the light beam deflected on the basis of a rotational characteristic particular to the deflector to move along the scanning plane surface at a constant speed and has both surfaces that are shaped to be spherical so that the curvature of field is close to zero or zero at any location on the scanning plane surface to the light beam.

(2) An optical scanning device according to Claim 1, wherein the thin light beam emitted from the light source is a parallel light beam prior to the incidence on the scanning lens.

3. Detailed Description of the Invention

[Industrial Field of the Invention]

The present invention relates to an optical scanning device for use in a laser beam printer or the like. More particularly, the present invention relates to a scanning lens system.

[Background of the Invention]

Laser beam printers, which deflects a laser beam for scanning to record scan image information at a high speed, have excellent features such as high-speed and high resolution recording of image information at a low noise level, and as their price goes down, the demand for the laser beam printers is rapidly growing. Accordingly, there is an increasing demand for smaller and low cost optical scanning devices serving as optical write heads which are an important component part of the printer. The component parts of an optical scanning device are roughly a light source, a deflector, and a scanning lens system, and the size and cost of optical scanning devices can be effectively reduced by simplifying the structure of the

optical lens system.

The scanning lens system must have a strain characteristic which allows an optical spot to move at uniform velocity along the scanning surface on the basis of the rotational characteristics of the deflector. For example, when the deflector is a rotating polygon mirror and the optical beam is being deflected at a uniform angular velocity, the strain characteristics of the scanning lens system is provided such that the deflecting angle θ and the image height Y are proportional to each other. In addition, the scanning lens system must be able to uniformly form an optical spot into an image of a predetermined size at any location on the scanning plane. Further when a rotational polygon mirror deflector is used, the scanning lens system must be able to compensate for variations that occur in the tilting of each face of the polygon (surface tilt). Consequently, conventional scanning lenses having the above-described characteristics as well as providing high resolution and performance were inevitably large, and complicated in structure, and costly.

[Description of the Related Art]

As disclosed in Japanese Patent Unexamined Publication Nos. 54-98627, 55-7727, 58-5706, and the like, attempts have been made to form the scanning lens into a

single lens. According to Japanese Patent Unexamined Publication No. 54-98627, when a deflector with a sinusoidally oscillating characteristic is used, it is possible to properly correct aberrations in terms of various parameter values of, for example, the shape thereof, making use of the rotational characteristics of the deflector. A rotating polygon deflector, now being widely used due to its high speed performance employs the lens formed in an aspherical shape to meet its constant angular speed rotational characteristics, and finds special applications under limitations, and the lens cannot be produced satisfying various requirements related to the dimensions of the optical system, the light source, the dot size or the like.

It cannot be really said that the scanning lens disclosed in Japanese Patent Unexamined Publication No. 55-7727, being a fθ plano-convex lens, has excellent imaging performance due to the curvature of field or the like.

The scanning lens disclosed in Japanese Patent Unexamined Publication No. 58-5706, being a fθ meniscus lens and having a positive refractive power, has a problem in that sagittal curvature of field occurs. To overcome such a problem, there must also be provided a cylindrical lens, which also functions as an optical system for correcting variations in the tilting of the surfaces of

the polygon mirror. In addition, in all of the above-described three examples, an additional lens must be provided in order to correct variations in the tilting of the surfaces, so that the lens system is no longer a single lens system. Though it is possible to increase the length of the optical axis and narrow the deflection angle to keep the aberration within tolerance, this is not preferable since this leads to an increase in the overall size of the optical system.

Consideration should be given to the material of the above-described lens systems. Conventional scanning lenses are made of glass. However, the use of glass results in high manufacturing costs, such as high grinding costs, since the optical system must be produced very precisely in order to provide the required diffraction limit performance. The use of, for example, polymethylmethacrylate (PMMA), polycarbonate, or polystyrene plastics makes it possible to mass-produce scanning lenses by injection molding at a very low cost. However, there are not many types of optical plastic materials, and plastic materials have a mall index of refraction compared to that of glass. Therefore, it is more difficult to produce a smaller optical system with fewer lenses compared to when glass is used to produce the optical system.

In summary, there is a demand for a lens system of a single lens having a shape with a high degree of freedom, which allows proper correction of aberrations even when its optical axis is short and regardless of the index of refraction of the material thereof.

[Problems to be Solved by the Invention]

In view of the above-described problems, an object of the present invention is to provide an optical scanning device and, more particularly, a scanning lens, which is low cost and provides high performance.

To this end, according to the present invention, there is provided an optical scanning device comprising a light source which emits a thin light beam, a deflector for deflecting the light beam in a predetermined direction in order to perform scanning, a scanning lens for imaging the light beam deflected by the deflector along a plane surface to be scanned. The scanning lens has strain characteristics allowing the light beam deflected based on the particular rotational characteristics of the deflector to move at a constant speed along the plane surface to be scanned, and comprises a single lens, both sides of which are aspherical so that the curvature of field is close to zero or zero at any location on the scanning plane surface. It is preferable that the thin light beam emitted from the light source is a parallel light beam.

[Means for Solving the Problem]

The optical scanning device of the present invention comprises a light source for emitting a thin light beam, a deflector for deflecting the light beam in a predetermined direction in order to perform scanning, and a scanning lens, being a single lens, for forming the light beam deflected by the deflector into an image on a scanning plane surface, wherein the scanning lens has a strain characteristic allowing the light beam deflected on the basis of a rotational characteristic particular to the deflector to move along the scanning plane surface at a constant speed, and has both surfaces that are shaped to be spherical so that the curvature of field is close to zero or zero at any location on the scanning plane surface to the light beam. The thin light beam emitted from the light source is preferably a parallel light beam prior to the incidence on the scanning lens.

[Description of the Embodiments]

A description will now be given of the principles of the present invention, with reference to Figs. 1 to 4.

The scanning lens has a strain characteristic which allows imaging of a light beam deflected by a deflector on the basis of, for example, a constant angular speed rotational characteristic or sinusoidal oscillation rotational characteristic along a scanning plane surface,

without any curvature of field, or scanning of an image point on the scanning plane surface at constant speed. For example, when the deflector is a rotating polygon mirror, as shown in Fig. 1, the light beam emitted from a light source is reflected by a mirror surface S_M at a deflecting angle of θ in accordance with the rotation of the polygon mirror 5. The scanning lens 1 is set such that the light beam forms an image at point T_1 on the scanning plane surface, where the coordinate value Y is proportional to the deflecting angle θ. The scanning lens of the present invention comprises a single lens having reduced aberration and allowing wide angle deflection, in which the advantages of making both surfaces S_1 and S_2 of the lens into aspherical surfaces, as shown in Fig. 1, are utilized to the utmost, based on the principles to be described below.

On the assumption that the scanning light beam is very thin, the first structural principle of the shape of the surface of the lens of the present invention is represented only by the parameters of the position and direction of the primary light beam and the imaging distance, in which the tilting and curvature are determined in terms of a point on the lens surface, while changing the direction or imaging distance for only the primary light beam that passes through the point. In

terms of correcting aberration, this means that the curvature of field and distortion including higher order terms are completely corrected while disregarding spherical aberration and coma. The above-described assumption generally holds true for the scanning optical system of, for example, a laser beam printer.

In addition, in the scanning lens system, the primary light beam deflected at any deflection angle is always on the same plane (called the meridional plane), so that based on the assumption that the light beam is very thin, the point where the tilting and the curvature are specified is on a curve formed where the meridional plane and the lens plane intersect each other. Therefore, according to the second structural principle of the present invention, generating a curve on the meridional plane and determining the tilting and the curvature within the meridional plane in terms of a point on the curve allows the above-described object of the scanning lens to be achieved. In addition, when the curvature on a cross sectional plane (sagittal cross section) perpendicular to the meridional plane, including the primary light beam, is determined in terms of the point, a surface is produced.

However, the lens surface position within the meridional plane is determined by continuously plotting the tilting and the curvature factors in the meridional

direction, so that they cannot be determined separately. However, the sagittal section curvature can be handled separately therefrom. Therefore, it is apparent that an optical system in which the form of the lens in the meridional plane alone is determined using the above-described first and second principles is also included within the scope of the present invention.

A description will now be given in detail of the structural principles of the lens in accordance with the present invention, with reference to the perspective view of Fig. 2.

Referring to Fig. 1, the light beam $\{L_{i-1}\}$ is converted into light beam $\{L_i\}$ by the surface S_i. The imaging distance measured from $\mathbf{T}_i$ of the light beam $\{L_i\}$ is represented by g_{mi} for the meridional light beam and by g_{si} for the sagittal light beam. In general, g_{mi} and g_{si} are not equal. Since the light beam $\{L_i\}$ is very thin as mentioned above, when the light beam $\{L_i\}$ is treated, only the primary light beam L_{ci} and the imaging distances g_{mi} and g_{si} for the meridional light beam and the sagittal light beam need, respectively, to be considered. The direction of the primary light beam L_{xi} after passage through the surface S_i can be controlled by normal direction of $\mathbf{e}_i$ at $\mathbf{T}_i$ of the surface S_i. The imaging distances g_{mi} and g_{si} can be controlled by the meridional section radius of

curvature R_{mi} and the sagittal section radius of curvature R_{si} at $\mathbf{T}_i$ of the surface S_i. Therefore, it is possible that a light beam deflected at a certain angle form an image at a location where scanning is performed at a constant speed on the scanning plane surface, based on the position and its differential value of one point on the lens surface (normal line direction and curvature). Differential quantities for other points are plotted in order to achieve imaging at locations where one light beam deflected at a certain angle can scan at a constant speed, whereby the shape of the lens is determined. This is the first structural principle.

As mentioned above, the primary light beam L_{CI} does not move away from the meridional plane, so that the normal line vector $\mathbf{e}_i$ of the surface S_i is also located within the meridional plane, with the degree of freedom of tilting being 1 at an angle of α_i formed by the optical axis and the normal vector, as shown in Fig. 2. Since the meridional section curvature of the surface S_i is the differential value of the tilting angle α_i of the surface S_i, and the tilting α_i is the differential value of the location of the surface S_i on the meridional plane, specifying the tilting and curvature of the surface in the meridional direction is after all the same as generating a two-dimensional curve on the meridional plane by solving a

differential equation. On the other hand, the sagittal section curvature is determined independent of the value of the above-described curve, so that after generation of the curve, the curvature is determined for each point on the curve. This is the second structural principle.

As can be understood from the foregoing description, the scanning lens is realized based on the above-described structural principles. The scanning lens may be a single lens whose surfaces are both aspherical in form, as illustrated in Fig. 3. Referring to Fig. 3, the figure plane represents the meridional plane.

Within the meridional plane, there are two degrees of freedom in which the coordinate value Y_1 of the point of intersection $\mathbf{T}_I$ of the primary light beam L_{ci} and the scanning plane surface S_1, and $\mathbf{T}_I$ form the imaging point. For example, in order to control the scanning position Y_1 of the light beam deflected by any angle θ, the tilting α_1 is specified of every location of the surface, and each factor is continuously plotted, so that when the boundary conditions (for example, that the tilting is zero at the coordinate value X_1 at the point of intersection P_1 with the optical axis) are specified, the lens shape is completely formed as surface S_1, with the result that the radius of curvature R_{m1} of that surface cannot be specified, causing the light beam to form an image at a

point T_I which is not on the scanning plane surface. On the contrary, when the radius of curvature R_{m1} of every location of the surface is specified in order to control the imaging point, the tilting α_1 of the surface cannot be specified. Accordingly, in order to control one degree of freedom among the various parameters of the light beam with any deflection angle θ, one surface is required, so that in order to control two degrees of freedom, at least two lens surfaces are required.

A description will now be given of sagittal light beams. One degree of freedom of the sagittal direction imaging distance g_{s1} is to be controlled, and can be controlled, while maintaining the shape of the curve, by generating a curve vertically to the curve on the meridional plane, so that it is not necessary to add another surface to the aforementioned two surfaces.

The lens system of a single lens with only two lens surfaces thus works. The tilting and curvature values have been determined for every location of the two lens surfaces, so that both surfaces of the single lens must be aspherical.

A description will now be given of the symmetry of the two aspherical surfaces of the single lens having the abovedescribed construction. When two curves are generated within the meridional plane and rotated around

an axis, such as the optical axis, as center, the degree of freedom of the radius of curvature in the sagittal direction is lost. Therefore, when the aspherical surfaces are made symmetrical, the imaging of the sagittal light beams cannot be controlled, resulting in sagittal curvature of field. Since the light beams are always located on the meridional plane, the surfaces are obviously symmetrical on the meridional plane. In addition, since when the deflecting angle of the light beam passing the optical axis is defined as 0, the light beam passing at an angle θ and that passing at an angle -θ pass under the same conditions, so that the surfaces are symmetrical with respect to a plane perpendicular to the meridional plane including the optical axis. Accordingly, the scanning lens of the present invention are not symmetrical except on the two planes, so that it is possible to completely correct sagittal curvature of field, meridional curvature of field, and distortion.

A description will now be given of a particular method for realizing the shape of the single scanning lens with aspherical surfaces of the present invention, with reference to Fig. 4. A description will also be given of a method for generating two curves on the meridional plane. Referring to Fig. 4, the lens surfaces S_1 and S_2 are defined by the relationship between the lengths S_1 and S_2

of the curves drawn from the intersection points P_1 and P_2 with the optical axis, respectively, and the tilting angles α_1 and α_2 measured from lines perpendicular to the optical axis. Describing this in terms of orthogonal coordinates, when the origins for the surfaces S_1 and S_2 are defined as P_1 and P_2, respectively, and the optical axis is defined as the x-axis and the direction of height of the lens as the y-axis, the coordinates (x_1, y_1), and (x_2, y_2) of points P_1 and P_2 are determined by Formula (1):

$$
\begin{aligned}
x_1 &= \int_0^{s_1} \sin\alpha_1 \, ds_1 \\
y_1 &= \int_0^{s_1} \cos\alpha_1 \, ds_1 \\
x_2 &= \int_0^{s_2} \sin\alpha_2 \, ds_2 \\
y_2 &= \int_0^{s_2} \cos\alpha_2 \, ds_2
\end{aligned} \qquad (1)
$$

As shown in Fig. 4, when the light beam L_i ($i = 0, 1, 2$), emitted from emitting point P_M on the optical axis at a deflecting angle θ and at a meridional imaging distance g_{m0}, intersects the surfaces at T_1 and T_2 on S_1 and S_2, respectively, in order to arrive at T_I of S_I, the location and direction of the outgoing light beam are expressed as follows:

$$P_M T_1 = \ell_0 \begin{pmatrix} \cos\theta \\ si\ \theta \end{pmatrix}$$

$$T_1 T_2 = \ell_1 \begin{pmatrix} \cos\theta_1 \\ si\ \theta_1 \end{pmatrix}$$

$$T_2 T_1 = \ell_2 \begin{pmatrix} \cos\theta_2 \\ si\ \theta_2 \end{pmatrix} \qquad (2)$$

The radius of curvatures of the meridional cross sections at T_1 and T_2 on the surfaces S_1 and S_2 are defined as R_{m1} and R_{m2}, and the meridional imaging distances are defined as g_{m1} and g_{m2}.

In accordance with the above-described method, the structural principle for the form of the aforementioned lens can be expressed in a formula which consists of six items described separately below.

(1) The light beam direction is controlled based on the tilting of the surfaces at the points of intersection of the light beam and the surfaces S_1 and S_2.

(2) The imaging distance of the light beam is controlled based on the curvature at the points of intersection of the light beam and the surfaces S_1 and S_2.

(3) Coordinates of the points of intersection of the light beam and the surfaces are the same.

(4) Each point is plotted continuously and smoothly along the surface.

(5) Light beam forms an image on the scanning plane surface.

(6) Imaging point on the scanning plane surface is scanned at a constant speed.

For (1), the relationships between the tilting of the refraction surface and the light beam direction are expressed by Formulas (3) and (4) by application of a well-known law of refraction to the intersection points of the surfaces S_1 and S_2 and L_1 and L_2.

$$\sin(\alpha_1-\theta)=n\sin(\alpha_1-\theta_1) \quad :S_1\ \mathit{surface} \qquad (3)$$

$$n\sin(\alpha_2-\theta_1)=\sin(\alpha_2-\theta_2) \quad :S_2\ \mathit{surface} \qquad (4)$$

where n is the index of refraction of the material of the lens.

For (2), the relationships between the curvature of the surface and the imaging distance of the light beam are determined by Formulas (5) and (6) by application of the relational formula of the meridional imaging distance measured when a thin light beam is directed obliquely to a curved surface to the S_1 and S_2 surfaces:

$$\frac{n\cos^2(\alpha_1-\theta_1)}{g_{m1}}=\frac{\cos^2(\alpha_1-\theta)}{g_{m0}-\ell_0}+\frac{n\cos(\alpha_1-\theta_1)-\cos(\alpha_1-\theta)}{R_{m1}} \qquad (5)$$

S1 surface

$$\frac{\cos^2(\alpha_2-\theta_2)}{g_{m2}}=\frac{n\cos^2(\alpha_2-\theta_1)}{g_{m1}-\ell_1}+\frac{\cos(\alpha_2-\theta_2)-n\cos(\alpha_2-\theta_1)}{R_{m2}} \qquad (6)$$

S2 surface

For (3), when the orthogonal coordinate values calculated in Formula (1) are equal to the orthogonal coordinate values of the refraction points of the light beam calculated by Formula (2), the following formulas (7), (8), (9) and (10) hold.

$$\ell_0\cos\theta=\int_0^{S_1}\sin\alpha_1 ds_1+X_1 \qquad (7)$$

$$\ell_0\sin\theta=\int_0^{S_1}\cos\alpha_1 ds_1 \qquad (8)$$

$$\ell_1\cos\theta_1+\ell_0\cos\theta=\int_0^{S_2}\sin\alpha_2 ds_2+X_2 \qquad (9)$$

$$\ell_1 \sin\theta_1 + \ell_0 \sin\theta = \int_0^{S_2} \cos\alpha_2 ds_2 \qquad (10)$$

In the formulas, X_1 represents the x coordinate of the point of intersection of the surface S_1 and the optical axis, and X_2 represents the x coordinate of the point of intersection of the surface S_2 and the optical axis.

For (4), the condition for forming a continuous surface is that the formulas (7) to (10) can be integrated. The condition for forming a smooth surface is that α_1 and α_2 can be differentiated. Therefore,

$$\frac{d\alpha_1}{ds1} = \frac{1}{R_{m1}} \qquad (11)$$

$$\frac{d\alpha_2}{ds2} = \frac{1}{R_{m2}} \qquad (12)$$

For (5), the image point on the scanning image plane surface is scanned at a constant speed, when the point of intersection (X_1, Y_1) of the image plane and the light beam is expressed by Formulas (13) and (14):

$$X_1 = \ell_2 \cos\theta_2 + \ell_1 \cos\theta_1 + \ell_0 \cos\theta \qquad (13)$$

$$Y_1 = \ell_2 \sin\theta_2 + \ell_1 \sin\theta_1 + \ell_0 \sin\theta \qquad (14)$$

and using the rotational characteristic of the deflector

expressed by Formula (15):

$$\theta = F(\tau) \qquad (15)$$

the scanning point position Y_1 is expressed by Formula (16):

$$Y_1 = K \bullet F^{-1}(\theta) \qquad (16)$$

where F^{-1} is an inverse function of F, τ is the time parameter, and K is an appropriate proportional constant. For example, when the rotational characteristic is a constant angular speed deflection, then as represented by Formula (17):

$$F(\tau) = \omega\tau \qquad \omega: \textit{angular velocity} \qquad (17)$$

Therefore,

$$Y_1 = K \bullet \frac{\theta}{\omega}$$

$$= f\theta \qquad f = \frac{K}{\omega}: \textit{constant} \qquad (18)$$

In Formula (13), the X represents the optical axis length to the x coordinate of the scanning surface.

For (6), the condition allowing image formation on the scanning plane surface is satisfied when the meridional light beam imaging distance g_{m2} of Formula (6) is equal to l_2 appearing in Formulas (13) and (14).

That is,

$$g_{m2}=\ell_2 \qquad (19)$$

As described above, the structural principles of the shape of a lens of the present invention are expressed by 14 Formulas, Formulas (3), (4), (5), (6), (7), (8), (9), (10), (11), (12), (13), (14), (16), and (19). When calculations are performed using these formulas, the shape of the lens can be directly expressed in some way. Of the variables appearing in the formulas, the deflecting angle θ, and the meridional imaging distance g_{m0} are known since they are determined when light is emitted. The optical axis length X_I, the points of intersection X_1 and X_2 of the surfaces S_1 and S_2 and the optical axis, and the constant speed scanning constant K are fixed values which do not depend on the deflecting angle θ. Therefore, the remaining 14 values θ_1, θ_2, α_1, α_2, s_1, s_2, g_{m1}, g_{m2}, l_0, l_1, l_2, R_{m1}, R_{m2} and Y_1 are unknown. The aforementioned 14 formulas are all independent, so that simultaneous equations are solved in order to allow the 14 variables above to be expressed as a function of, for example, the deflecting angle θ. Therefore, for example, when the surface S_1 is to be expressed, the surface S_1 is placed in opposition to the relationship between the tilting α_1 and the distance S_1 measured along the surface from the optical

axis, with the deflecting angle θ as parameter.

The above-described 14 element simultaneous equations are non-linear and includes differential as well as integral terms, so that they cannot be directly solved, making it necessary to use numerical solution methods. There are various numerical solution methods, and the present invention is not limited to a particular numerical solution method. Numerical integration in a differential vector field will be described as an example thereof in order to actually solve the equation numerically, whereby the shape of the lens is obtained.

Calculation in a differential vector field means to determine the next variable as a result of expressing all of the equations in differential form, so that all of the present variables known, and calculating the differentials thereof. When the 14 equations are expressed in differential form, Formulas (3) and (4) are transformed into Formulas (20) and (21):

$$(d\alpha_1 - d\theta)\cos(\alpha_1 - d\theta) = n(d\alpha_1 - d\theta_1)\cos(\alpha_1 - \theta_1) \qquad (20)$$

$$n(d\alpha_2 - d\theta_1)\cos(\alpha_2 - \theta_1) = (d\alpha_2 - d\theta_2)\cos(\alpha_2 - \theta_2) \qquad (21)$$

Combining Formulas (5) and (6) and Formulas (11) and (12), respectively, results in Formulas (22) and (23):

$$\frac{n\cos^2(\alpha_1-\theta_1)}{g_{m1}}ds_1=\frac{\cos^2(\alpha_1-\theta_1)}{g_{m0}-\ell_0}ds_1+\{n\cos(\alpha_1-\theta)-\cos(\alpha_1-\theta)\}d\alpha_1 \quad (22)$$

$$\frac{\cos^2(\alpha_2-\theta_2)}{g_{m2}}ds_2=\frac{\cos^2(\alpha_2-\theta_1)}{g_{m1}-\ell_1}ds_2+\{\cos(\alpha_2-\theta_2)-n\cos(\alpha_2-\theta_1)\}d\alpha_2 \quad (23)$$

where g_{m1} are eliminated by solving the equations (22) and (23) as a simultaneous equation.

Formulas (7) to (10) are respectively transformed in Formulas (24) to (27):

$$d\ell_0\cos\theta-\ell_0\sin\theta d\theta=\sin\alpha_1 ds_1 \quad (24)$$

$$d\ell_0\sin\theta+\ell_0\cos\theta d\theta=\cos\alpha_1 ds_1 \quad (25)$$

$$d\ell_1\cos\theta_1-\ell_1\sin\theta_1 d\theta_1+d\ell_0\cos\theta-\ell_0\sin\theta d\theta=\sin\alpha_2 ds_2 \quad (26)$$

$$d\ell_1\sin\theta_1+\ell_1\cos\theta_1 d\theta_1+d\ell_0\sin\theta+\ell_0\cos\theta d\theta=\cos\alpha_2 ds_2 \quad (27)$$

Formulas (13) and (14) are transformed in Formulas (28) and (29):

$$0=d\ell_2\cos\theta_2-\ell_2\sin\theta_2 d\theta_2+d\ell_1\cos\theta_1-\ell_1\sin\theta_1 d\theta_1+d\ell_0\cos\theta-\ell_0\sin\theta d\theta \quad (28)$$

$$dY_1=d\ell_2\sin\theta_2+\ell_2\cos\theta_2 d\theta_2+d\ell_1\sin\theta_1+\ell_1\cos\theta_1 d\theta_1+d\ell_0\sin\theta+\ell_0\cos\theta d\theta \quad (29)$$

Formula (16) is transformed into Formula (30):

$$dY_1 = K\{F^{-1}(\theta)\}d\theta$$

Formula (19) only needs to be substituted. In Formulas (20) to (30) , the unknown differential variables are $d\theta_1$, $d\theta_2$, $d\alpha_1$, $d\alpha_2$, ds_1, ds_2, dl_0, dl_1, dl_2, and dY_1. Formulas (20) to (30) are all first degree equations, except Formulas (22) and (23) which are formed into a simultaneous equation of the second degree, so that they can be easily solved. For example, $d\theta_1$ can be expressed by Formula (31) on the basis of the known differential variable $d\theta$:

$$d\theta_1 = F\theta_1(\theta_1, \theta_2, \alpha_1, \alpha_2, s_1, s_2, \ell_0, \ell_1, \ell_2) \cdot d\theta \qquad (31)$$

Therefore, when, for example, θ_1 is integrated as in Formula (32):

$$\theta_1 = \int_0^{\theta} F\theta \, d\theta + \theta^{\circ}1 \qquad (32)$$

the deflecting angle θ can be expressed as a parameter. Here, $\theta^{\circ}{}_1$ represents an initial value. In the actual calculation, the initial value can be calculated by numerical integration, when θ_1, θ_2, α_1, α_2, s_1 and s_2 are defined as zero, and l_0, l_1, and l_2 are transformed using the aforementioned X_1, X_2, and X_1, so that as in Formula (33):

$$\begin{aligned} \ell^{\circ}{}_0 &= X \\ \ell^{\circ}{}_1 &= X_2 - X_1 \\ \ell^{\circ}{}_2 &= X_1 - X_2 \end{aligned} \qquad (33)$$

The meridional plane curve of the shape of the lens of the present invention has been described in detail above. The constants n, X_1, X_2, X_I, g_{mo}, and K that have appeared in the description are the degrees of freedom that the shape of the lens of the present invention can take. More specifically, one lens shape exists for one proper set of constants {X_1^*, X_2^*, X_I^*, g_{m0}^*, K^*}, making it obvious that all the lens shapes defined by the different sets including these constants are included within the scope of the present invention.

The meridional initial imaging distance g_{m0}^* is set at infinity. More specifically, when the meridional light beam before entrance into the scanning lens is assumed as being a parallel light beam, the beam diameter or the like becomes very easy to control, thus making the optical system easy to handle. It is obvious that the scanning lens of the present invention can also be applied to parallel light beams.

A description will now be given of the method of determining the sagittal cross section curvature radius R_{s1} and R_{s2} for controlling the sagittal imaging distance. The relational formulas of the meridional imaging distances for a thin light beam obliquely entering a surface has been expressed in Formulas (5) and (6). For the sagittal imaging distances, the Formulas (34) and (35) hold:

$$\frac{n}{g_{s1}}=\frac{1}{g_{s0}-\ell_0}+\frac{n\cos(\alpha_1-\theta_1)-\cos(\alpha_1-\theta)}{R_{s1}} \quad (34)$$

S1 SURFACE

$$\frac{1}{g_{s2}}=\frac{n}{g_{s1}-\ell_1}+\frac{\cos(\alpha_2-\theta_2)-n\cos(\alpha_2-\theta_1)}{R_{s2}} \quad (35)$$

S2 SURFACE

In order for an imaging point in the sagittal dimension to be present on the scanning plane surface, the following condition must hold:

$$g_{s2}=\ell_2 \quad (36)$$

The sagittal section curvature radius R_{s1} and R_{s2} are determined using Formulas (34), (35), and (36). In the formulas, l_0, l_1, l_2, α_1, α_2, θ, θ_1, and θ_2 are known since the meridional plane curvatures have been already determined by the aforementioned method, and g_{s0} has already been given, so that there are four unknown terms g_{s1}, g_{s2}, R_{s1}, and R_{s2}. Therefore, there is a redundant degree of freedom with respect to the three formulas, and a suitable value is set for one of the unknown terms. For example, in order to form a simple surface shape, when R_{s1} is always set at infinity and the second term from the right side of Formula (34) is 0, the first surface will not be curved in the sagittal dimension.

The initial sagittal imaging distance g_{s0} can be given

any value, but when a deflector is a rotating polygon mirror, making

$g_{s0} = 0$

allows correction of surface tilting since the mirror reflecting point and scanning point form a conjugate image point.

[Examples]

A description will now be given of the Examples in which calculations have been made of the lens surfaces based on the structural principles for the shapes of the lens of the present invention, with reference to Tables 1 to 9 and Figs. 5 to 12.

As described above, in determining the shape of the lens of the present invention, six parameters including the index of refraction n of the lens material, the initial imaging distance g_o, the intersection positions X_1 and X_2 of the first and second lens surfaces and the optical axis, the optical axis length X_I, and the scanning speed constant K, can be independently varied, with one set of parameters defining one lens shape. Therefore, it would seem that there are a great number of examples of lens with completely different lens shapes. Since it is impossible to present all these examples, only typical examples thereof will be given.

Calculations in the following Examples are performed

under the following conditions.

- Index of refraction of lens material: n = 1.486
- Optical axis length measured from deflecting point to scanning plane surface: X_I = 200 mm
- Deflector is a rotating polygon mirror and deflects at constant speed
- Initial meridional imaging distance g_{m0} is set at infinity. That is, the light beam that has not entered the scanning lens is a parallel light beam.
- Only the second surface has a sectional curvature in the sagittal dimension.
- Initial sagittal imaging distance g_{s0} is 0. Therefore, the rotating polygon mirror reflecting point and the scanning point form a conjugate image point, allowing it to correct surface tilting.

The shape of the lens, which cannot be determined easily using simple numerical values or numerical expressions, is determined from, for example, the results of a numerical example. For convenience, the curvature on the meridional plane is determined using the known aspherical plane coefficient:

$$x=\frac{\frac{y}{R}}{1+\sqrt{1-(\frac{y}{R})^2}}+By^4+Cy^6+Dy^8+Ey^{10}$$

where x is the x coordinate when the x axis is defined by

the optical axis, and the point of intersection of the surface and the optical axis is defined as the origin.

The sagittal surface curvature R_{s2} is determined by the following formula:

$$R_{s2}=R_{s2}^{0}+Ay^{2}+By^{4}+Cy^{6}+Dy^{8}+Ey^{10}$$

When the shape of the lens approximates that of the true shape, the error is from about 0.001% to 0.01%.

In Tables 1 to 3, the coefficients R_{m1}, B_1, C_1, D_1, and E_1 defining the shape of the curve on the meridional plane of the first surface S_1, in Tables 4 to 6 the coefficients R_{m2}, B_2, C_2, D_2 and E_2 defining the curvature on the meridional plane of the second surface S_2, and in Tables 7 to 9 the coefficients $R^{\circ}{}_{s}$, A_s, B_s, D_s, and E_s defining the changes in the radius of curvature in the sagittal section dimension are determined, changing the parameters θ_e, X_1, and X_2. When a parameter is used in place of the scanning speed coefficient K of Formula (18), and the effective scanning width is set at 200 mm, the effective deflecting angle θ_e is determined by the following formula.

$$\theta_e=\frac{200}{K} \qquad (rad)$$

where X_1 and X_2 define the points of intersection of the first surface S_1 and the second surface S_2, respectively, and the optical axis. The calculations are performed

under the same conditions and the same values are used for θ_e, X_1, and X_2 in the parameter set, and the lenses have the same shape. The curvatures on the meridional plane and the optical paths in several of the Examples represented by the tables are illustrated in Figs. 5 to 12. The curve of each is symmetrical with respect to the optical axis, so that the opposite side of each is not illustrated.

On the basis of the structural principles of the present invention, the lenses of the Examples are all completely corrected for sagittal curvature of field, and meridional curvature of field, and have strain characteristics which are completely determined such that the scanning point moves at a constant speed.

The above-described aberrations are completely corrected in ideal lenses, so that in actual lenses curvature of field or distortion occur to a certain degree since errors do occur when numerically calculating the shape of and manufacturing the actual lens. Obviously, there are certain tolerances within which the aberrations must lie, so that when the aberrations are within these tolerances, the scanning lens is an effective lens. Therefore, scanning lenses in which aberrations occur to a certain degree are not excluded from the scope of the present invention.

Fig. 13 is a perspective view of the entire optical system of the printer laser beam, utilizing an embodiment of a lens shape in accordance with the present invention. A light beam leaving a semiconductor laser 2 is collimated into a parallel beam by a collimator lens 3, and is gathered only in the sagittal dimension by a cylindrical lens 4 in order to linearly form an image and near the mirror surface of a rotating polygon mirror deflector 6. After the light beam has been deflected at a constant angular speed within the meridional plane, and has passed through a scanning lens 1, an image is formed on a photoconductive drum 7. In the sagittal dimension, the mirror surface and the photoconductive drum surface form a conjugate image point, so that the optical system is capable of correcting surface tilting. The image point is scanned at a constant speed in the axial dimension of the photoconductive drum 7 by the scanning lens 1 of the present invention, so that an image is formed along a straight line, without any curvature of field. The photoconductive drum repeatedly rotates one pitch at a time upon completion of a scanning, whereby a latent image is formed on the photoconductive drum.

[Advantages] As can be understood from the foregoing description, in the optical scanning device of the present invention, the scanning lens has a strain characteristic

allowing the light beam to move at a constant speed along the scanning plane surface, and is a single lens, both sides of which are aspherical so that curvature of field is zero or almost zero when a light beam scans a scanning plane surface. Therefore, even when the scanning lens is a single lens, the lens is capable of providing an excellent imaging spot with almost no aberrations, allowing wide angle deflection, and has a short optical axis length. In addition, for the same reason, the use of a lens material with a low index of refraction does not affect the designing of the lens in any way, so that plastic material can be used for the lens. Therefore, the optical scanning device is reduced in size and cost, and provides high performance.

[BRIEF DESCRIPTION OF THE DRAWINGS]

Fig. 1 is a schematic view of the construction of an optical scanning device in accordance with the present invention, Fig. 2 is illustrative of the structural principles of a shape of the lens in accordance with the present invention, Fig. 3 is a view illustrating the fact that the scanning lens of the present invention can be a single lens, both surfaces of which are aspherical, Fig. 4 is illustrative of a method of calculating the shape of the scanning lens of the present invention, Figs. 5 to 12 are views illustrating the shapes of the lenses of the

examples of the present invention, and Fig. 13 is a perspective view of an embodiment of the entire light scanning device of the present invention.

1 ... Scanning lens, 2 ... Semiconductor laser, 5 ... Polygon mirror, 6 ... Rotating polygon deflector, 7 ... Scanning surface (photoconductive drum)